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GEOPHYSICS

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The Society of Exploration Geophysicists

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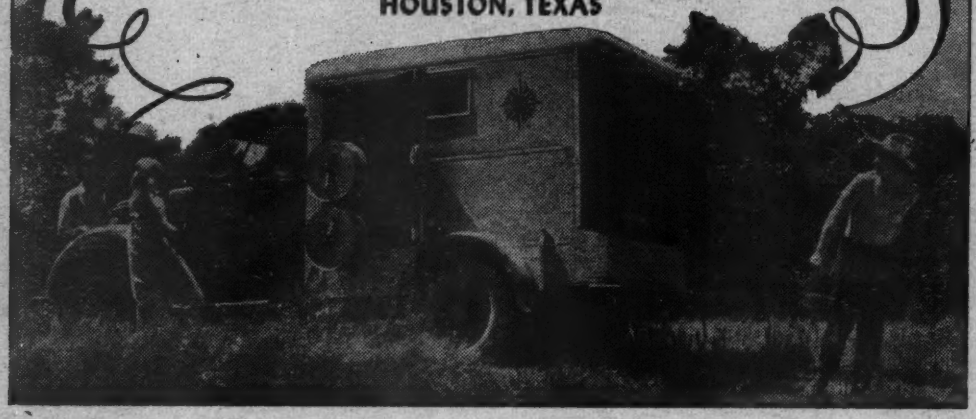

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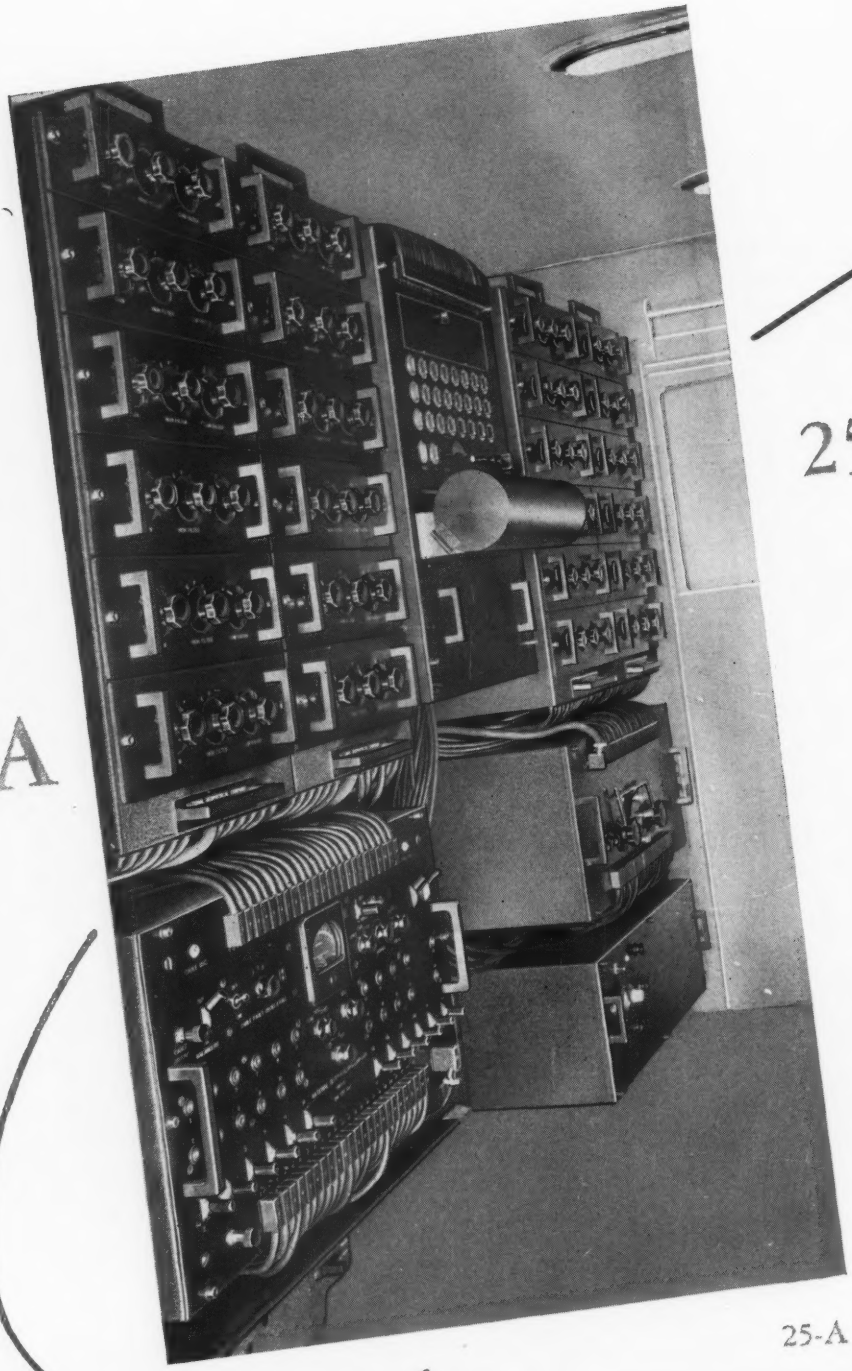

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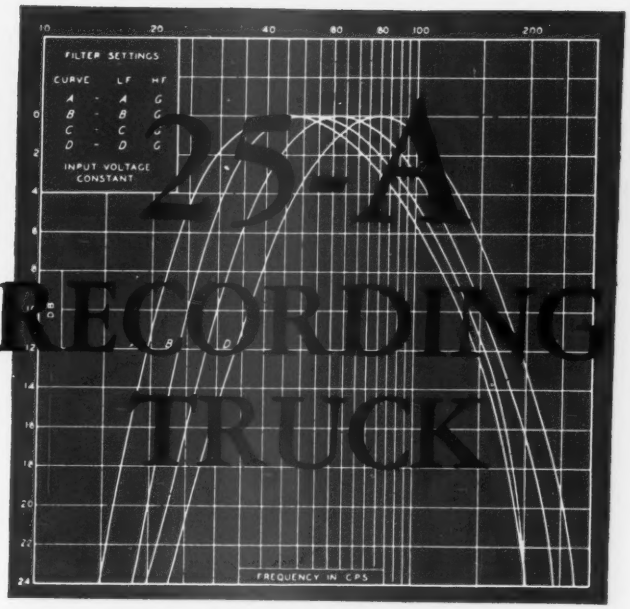

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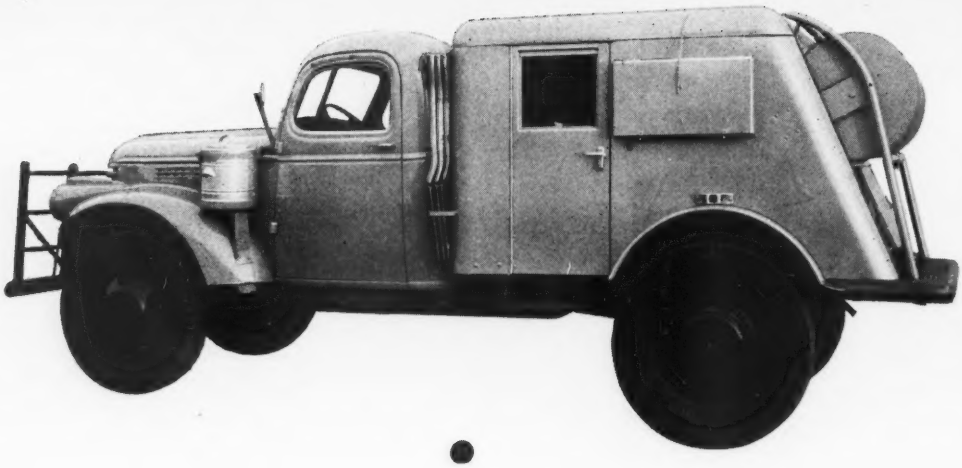

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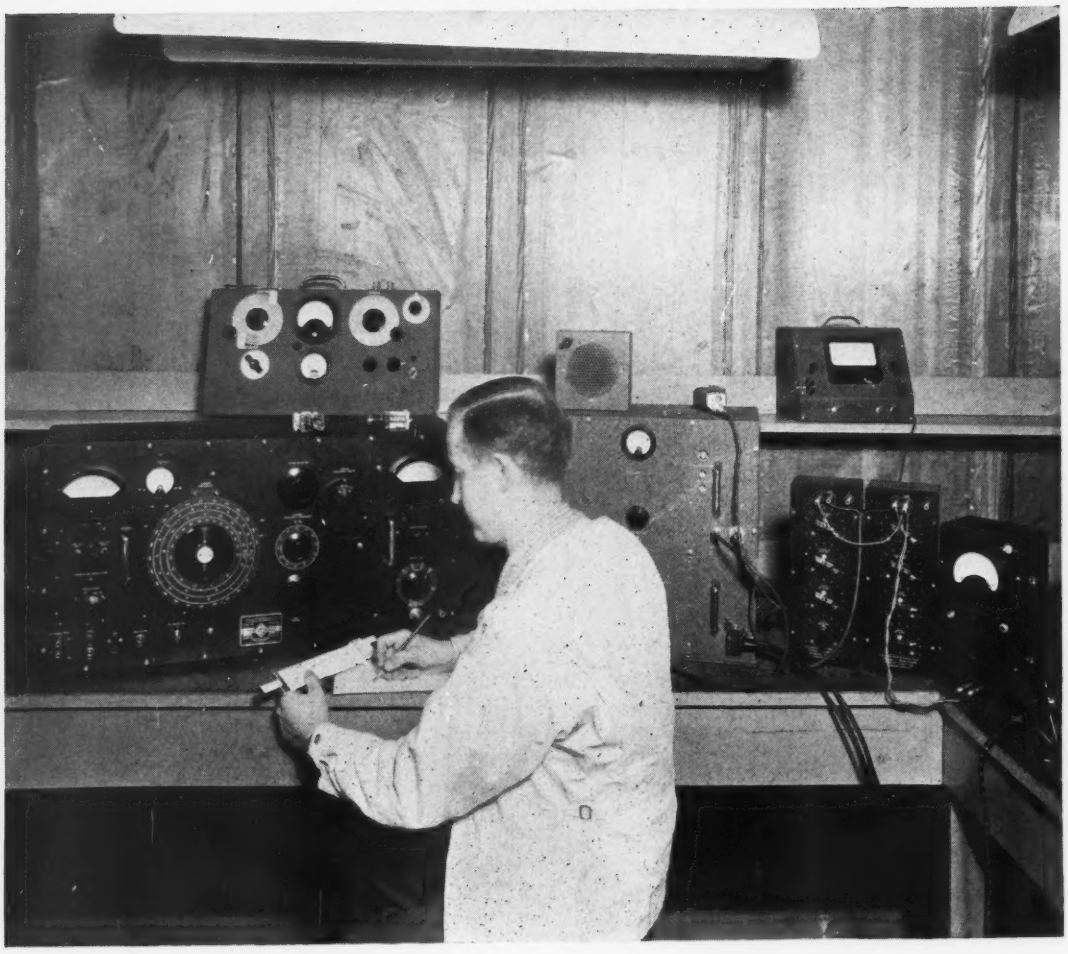

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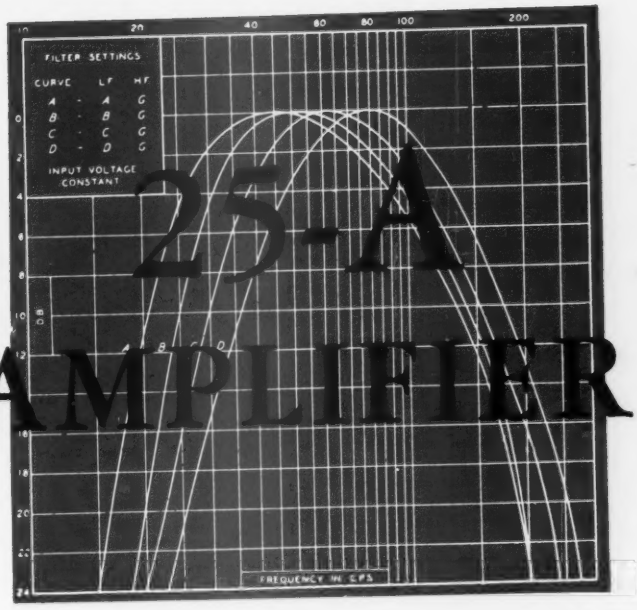

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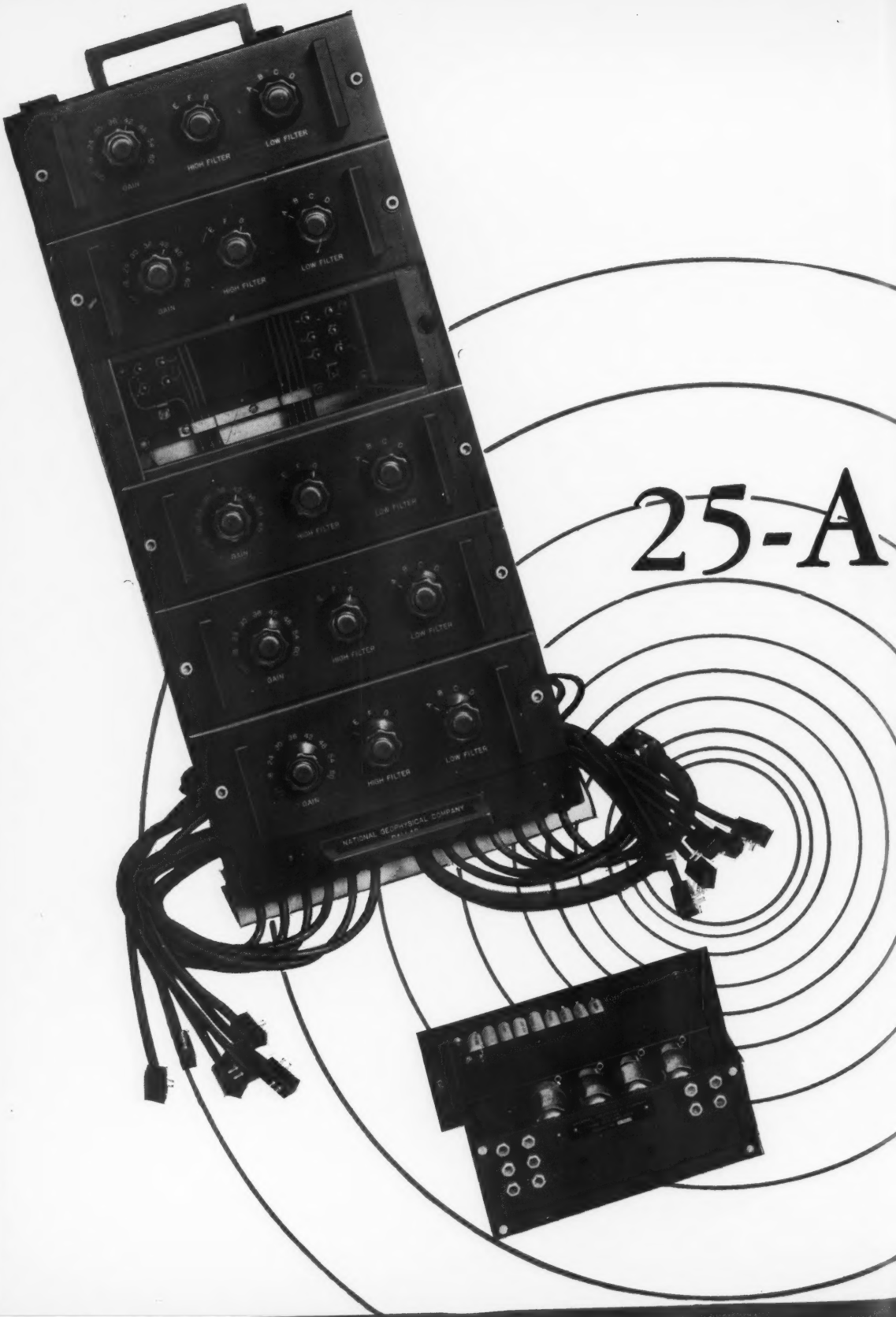
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Size of amplifier case—
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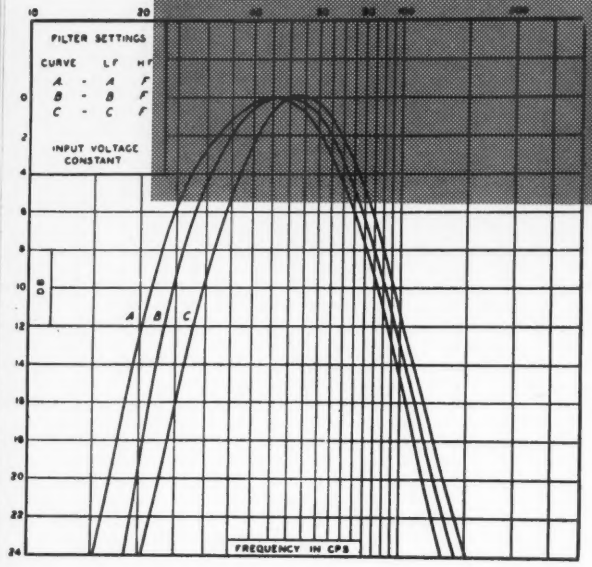

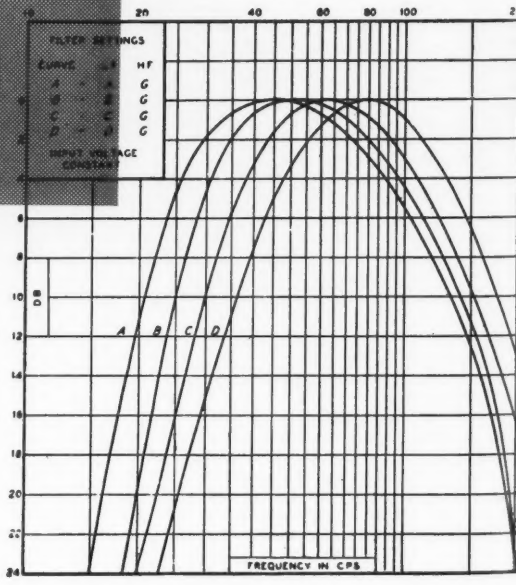

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VOLUME X OCTOBER, 1945 NUMBER 4

GEOPHYSICS

A Journal of General and Applied Geophysics

REPEATED P-WAVES IN SEISMIC EXPLORATION* OF WATER COVERED AREAS

ROY L. LAY†

ABSTRACT

A secondary, and even a tertiary, P-wave has been observed under certain conditions in seismic exploration of water covered areas. It is shown that these events are caused by an oscillation at the shot point. The procedure for eliminating these disturbing phenomena is described.

Some years ago in the course of seismic exploration of West Cote Blanche Bay, St. Mary Parish, Louisiana, a serious difficulty was encountered in reproducing reflection records at the same recording setup, using various sized dynamite charges. An examination of the records showed the occurrence of a wave with the same apparent velocity as the P-waves, but following the P-wave by a time interval which depended on the size of the charge. In many cases this secondary P-wave was almost comparable in amplitude to the first P-wave, having associated with it a series of reflections shifted by the same time interval as the secondary P-wave. It was obvious that a repeated pulse was originating at the shot point, resulting in two or more complete records superimposed on each other.

It was only natural to study this problem by taking a series of records under identical conditions, the only variables being the size and depth of the charge. A set of such records is shown in Figure 1. where the secondary P-wave can be seen quite clearly on some of the records. A tertiary P-wave is quite clear on Record 2 and no secondary P-wave is present on Record 4. The charges used on the four records

* Read at the Houston and Dallas meetings of the Society, 1945.

† The Texas Company, Houston, Texas.

were two, five, twenty and forty pounds, respectively. It should be mentioned here that the relative amplitudes between the four records cannot be compared, inasmuch as amplitude control was used in order to bring out more clearly the repeated P-waves. It was found that the time interval between the first and the second P-wave increased with the charge. Figure 2 shows graphically this relationship between the time interval and charge, for a depth of 15 feet, on a logarithmic scale,

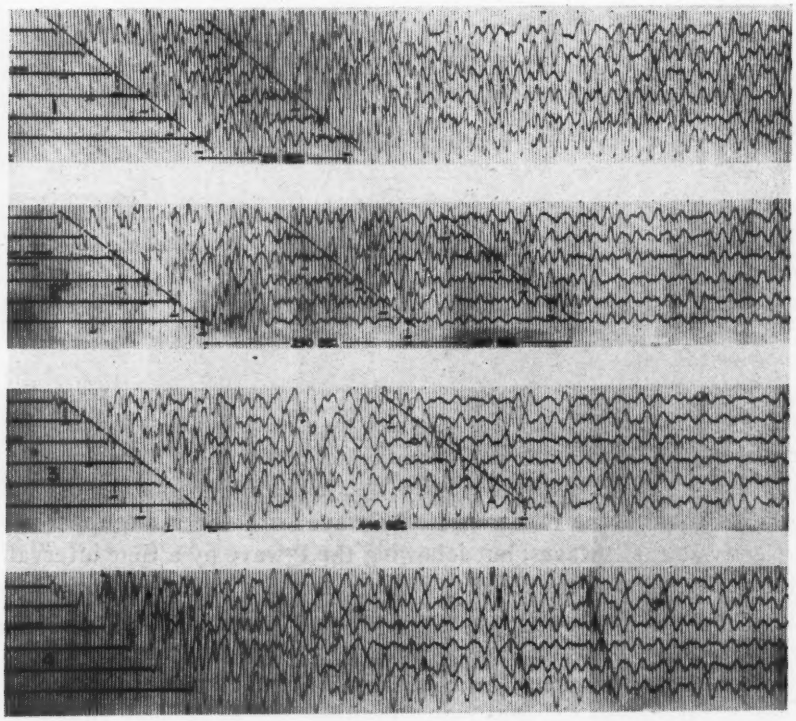


FIG. 1. Seismograph records 1, 2, 3, and 4, from shots of 2, 5, 20 and 40 pounds, respectively, in water. Secondary P-Waves on records 1, 2, and 3. Tertiary P-Waves on record 2. No repeated waves on record 4.

the time interval varying as the cube root of the charge. It is interesting to note that if an assumption is made that the charge of explosive is converted into a spherical volume of gas at a pressure and temperature independent of the size of the charge, then the radius of this sphere would be proportional to the cube root of the charge, and there-

fore the time interval would turn out to be proportional to the radius of this spherical gas bubble.

Such a vague theoretical consideration led to the supposition that the problem here was an oscillation of a spherical volume of gas with a period proportional to the radius of the bubble at a given pressure. The next supposition which was made was that the oscillation could be prevented by bringing the charge close enough to the surface of the water, so that the gas bubble would burst through the surface on first expansion; the same effect could be accomplished by increasing the charge, and thereby increasing the radius of the bubble so that the surface would break before the contraction could occur.

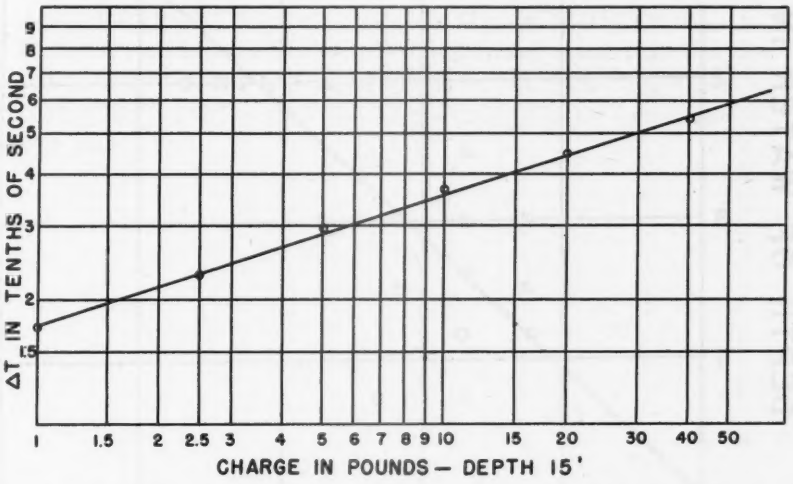


FIG. 2. Relation of time interval between first and second P-Waves to charge.

In order to clarify this matter a series of experiments was undertaken in which charges of various sizes were fired at various depths in water, with other conditions remaining unchanged. Figure 3 is a chart in which the ordinate and abscissa are depth of shot below the water surface and size of charge, respectively, and a triangle or circle indicates whether a secondary P-wave did or did not occur. The circles and triangles are divided by a straight line running through the origin. The equation of this line is Depth of Water $= 3.8$ (charge)$^{1/3}$ One might argue, though without sufficient theoretical justification, that this line represents the radius of the gas bubble at its extreme expansion. If the depth of water above the charge exceeds the radius

of the bubble an oscillation occurs. If the depth of the water above the charge is less than the radius of the bubble, the bubble breaks through the surface of the water and there is no oscillation. This condition is shown by Record 4 of Figure 1 which was taken with a charge of

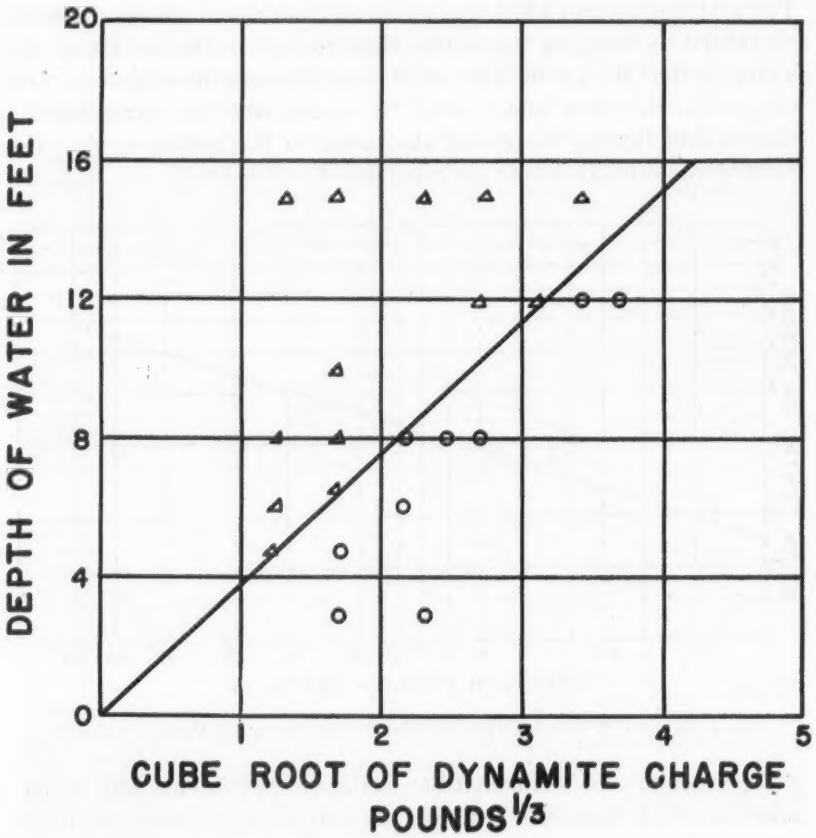


FIG. 3. Relation of size and depth of charge to production of secondary P-Waves. Shots of depth and size indicated by triangles produced repeated P-Waves; those indicated by circles did not produce repeated P-Waves.

forty pounds at a depth of 12 feet and no secondary P-waves occur as on the smaller charges of Records 1, 2 and 3. Regardless of what hypothesis one might formulate, the practical aspect of the situation is that when conducting exploration in water flooded areas one must be certain that the point representing the charge-depth relation

falls in the lower part of the diagram shown in Figure 3. If the depth is fixed, this can be accomplished by increasing the charge sufficiently, but it should be noticed that in very deep water this may not be practical, because at a depth such as 38 feet at least 1,000 pounds of explosives would be required to prevent oscillation, based on an extrapolation of the line in Figure 3. Thus in very deep water it is necessary to float the charge at a reasonable depth.

The phenomenon described above has been observed only with the charge located in water or a very soft mud and not when the charge was placed on a hard bottom, no matter how deep the water. It is possible that spherical symmetry of the gas bubble is required to produce the oscillation and accompanying multiple events.

Acknowledgment is hereby made to Messrs. B. H. Treybig, Jr., L. M. Hubby and L. G. Cowles, who contributed toward the solution of this problem, to Dr. Alexander Wolf for valuable suggestions in preparing this paper, and to the Texas Company for permission to publish same.

EFFECT OF RAY CURVATURE UPON SEISMIC INTERPRETATIONS*

E. J. STULKEN†

ABSTRACT

With theory of seismic paths fairly well established and with errors due to neglect of ray curvature considered in general terms or isolated examples by several authors, there remains a need for extended calculations measuring the effect of curvature. For a specific family of velocity functions inaccuracies of velocity computations based on straight path assumptions are illustrated graphically. Discrepancies traceable to use of straight line methods of depth, dip and offset determination are likewise described.

Certain fallacies attending the application of simple curved path procedure to seismic prospecting are considered briefly so that a reasonably fair evaluation of net importance of the ray curvature problem may be attempted.

EXPLANATORY REMARKS

In seismic reflection prospecting it is common practice to avoid certain mathematical refinements in favor of simpler, more flexible empirical computation procedures. This practice is defensible in many instances, but it is highly desirable to be able to account for discrepancies introduced thereby. Among the more elusive errors are those associated with the approximation of actual travel paths by straight lines. That many men have concerned themselves with problems related to such approximations can be seen by inspection of geophysical literature.

The purpose of this paper is not to extend theory beyond the scope revealed by these men but rather to provide some evaluations of the errors traceable to neglect of path curvature. The desideratum is, of course, to set forth the various quantities in terms general enough to encompass velocity functions with all manner of existing complexities. Though this goal appears unattainable at present, simplified theoretical approximations to actual field conditions provide a fair working basis.[1,2]

To begin, let us assume that velocity is completely described in terms of depth and initial velocity of section by the parabola

* Read at 1945 Meetings of the S.E.G. in Houston and Dallas, Texas.

† Geophysical Service Inc., Dallas, Texas.

[1] Slotnick, M. M., *On Seismic Computations with Applications*, GEOPHYSICS, Vol. I, No. 1, pp. 9–22 (Jan. 1936), and No. 3, pp. 299–305 (Oct. 1936).

[2] Mott-Smith, M., *On Seismic Paths and Velocity-Time Relations*, GEOPHYSICS, Vol. IV, No. 1, pp. 8–35 (Jan. 1939).

$$V = V_0(1 + KZ)^{1/2}. \tag{1}$$

Relations developed by Romberg or Houston show that travel time, horizontal displacement, and vertical displacement of a point moving from a specific origin on the surface with this speed are respectively:

$$T = 2(\phi - \phi_0)/V_0K \sin \phi_0, \tag{2}$$

$$Y = (\phi - \sin \phi \cdot \cos \phi - \phi_0 + \sin \phi_0 \cdot \cos \phi_0)/K \sin^2 \phi_0, \tag{3}$$

$$Z = (\sin^2 \phi - \sin^2 \phi_0)/K \sin^2 \phi_0. \tag{4}$$

Here ϕ_2 denotes the direction of the path at the top of the section and ϕ its direction at the depth Z, both measured with respect to vertical.[3,4] Equation 2 may be replaced by the relation

$$V_0T = 2(\phi - \phi_0)/K \sin \phi_0 \tag{5}$$

In order to facilitate expression of results for the entire family of parabolic velocity functions.

VELOCITY FROM SURFACE MEASUREMENTS

In the straight path method of computing average velocity from reflection profiles the formula

$$\overline{V}_t = (X_2^2 - X_1^2)^{1/2}/(T_2^2 - T_1^2)^{1/2} \tag{6}$$

is generally utilized wherein X_2 and X_1 represent different spreads or shot-to-seismometer distances at which T_2 and T_1 are the respective travel times observed from a particular reflecting surface assumed herein to be horizontal.[5] For a function which is actually parabolic Fig. 1, by way of example, indicates the error in average velocity computations due to neglect of path curvature when reflection time differences are utilized between a seismometer at the shot point and a second one 2000 feet away. The error is expressed as the ratio of computed to true average velocity, $\overline{V}_t/\overline{V}$, in terms of V_0T_2 with a separate line for each designated K. The relation of V_0T_2 to T_2 is shown by an auxiliary scale to the left and a second set of lines corresponding to various initial velocities. Construction of Fig. 1 is based essentially on use of the

[3] Houston, Charles E., *Seismic Paths, Assuming a Parabolic Increase of Velocity with Depth*, GEOPHYSICS, Vol. IV, No. 4, pp. 242–246 (Oct. 1939).

[4] Romberg, F. E., Papers in private circulation.

[5] Romberg, F. E., *The Probable Errors of Delta-T Velocities*, GEOPHYSICS, Vol. VI, No. 4, pp. 356–369 (Oct. 1941).

parametric Eqs. 3, 4, and 5, along with substitution of derived quantities into Eq. 6 divided by $\overline{V}$.[6]

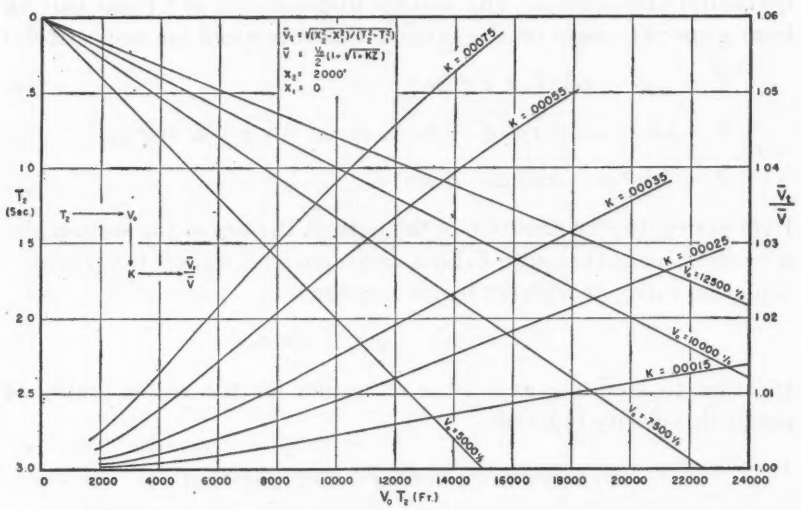


FIG. 1. Ratio of average velocity $\overline{V}_t$, given by straight path computations based on reflection times, to true average velocity $\overline{V}$. The illustration applies to reflections from horizontal beds above which $V = V_0(1+KZ)^{1/2}$.

The magnitude of $\overline{V}_t/\overline{V}$ for significant values of K demands attention. For example, for

$$V = 6250\ (1 + 0.0003Z)^{1/2} \tag{7}$$

Fig. 1 shows the following ratios:

T_2	$\overline{V}_t/\overline{V}$
.5	1.002
1.5	1.011
2.5	1.022

Over observed ranges of K, V_0 and T_2 discrepancies range roughly from 25 feet per second to over 250 feet per second, with straight path results consistently too large.

These magnitudes may be construed to mean that usual methods of computing average velocity from time differences stand in need of revision if resulting velocity determinations are to be applied to situa-

[6] Jakosky, J. J., Exploration Geophysics, Times-Mirror Press, 1940, pp. 528–530.

tions where high standards of accuracy are demanded. One adjustment that might be worthy of trial would utilize successive approximations of average velocity by means of Equation 6 and use of a graph similar to the one illustrated, constructed for the particular spread employed. That a relatively simple adjustment of some kind may be practical seems especially likely in view of a remarkable insensitiveness of the ratio $\overline{V}_t/\overline{V}$ to spread. The increase is comparatively slight with an increase in the larger shot-to-seismometer distance. At the same time application of any adjustment for path curvature should be considered only in conjunction with other sources of inaccuracy of velocity determinations enumerated by Steele, since partially compensatory relationships may exist.[7]

WELL VELOCITY SURVEY COMPUTATIONS

Of less concern is the disparity embodied in the generally accepted straight path method of computing well surveys by dividing travel time into the distance from seismometer to a point in the neighborhood of the shot. Fig. 2 illustrates magnitudes to be expected granting that velocity may be represented in parabolic form. The ratio of average velocity by straight path methods to the correct average velocity, $\overline{V}_w/\overline{V}$, is so near unity as to be negligible.

Even for the specific function

$$V = 5750\,(1 + 0.00055Z)^{1/2}, \tag{8}$$

which because of its large K provides an extravagant measure, the disagreement is negligible for spreads shown in Fig. 3. In general observational errors greatly outweigh the discrepancies indicated in these two figures.

STRAIGHT PATH COMPUTATIONS FOR DEPTH, DIP, AND OFFSET

Another interesting phase of path curvature effects concerns the conversion of travel time observations to various distance relationships. A number of empirical straight path methods are in use, as explained by Alcock and others.[8,9] In order to proceed with the remain-

[7] Steele, W. E., Jr., *Comparison of Well Survey and Reflection "Time-Delta Time" Velocities*, GEOPHYSICS, Vol. VI, No. 4, pp. 370–377 (Oct. 1941).

[8] Alcock, E. D., *Selection of Computational Methods for Seismic Paths*, GEOPHYSICS, Vol. VIII, No. 3, pp. 297–307 (July 1943).

[9] Gaby, Phil P., *A New Type of Seismic Cross-Section Wherein Accuracy of Representation Is Rendered Insensitive to Velocity Error*, GEOPHYSICS, Vol. X, No. 2, pp. 171–185 (April 1945).

ing analysis, it is convenient to choose a particular procedure such as the one illustrated in Fig. 4, wherein dip is taken to be slope of the

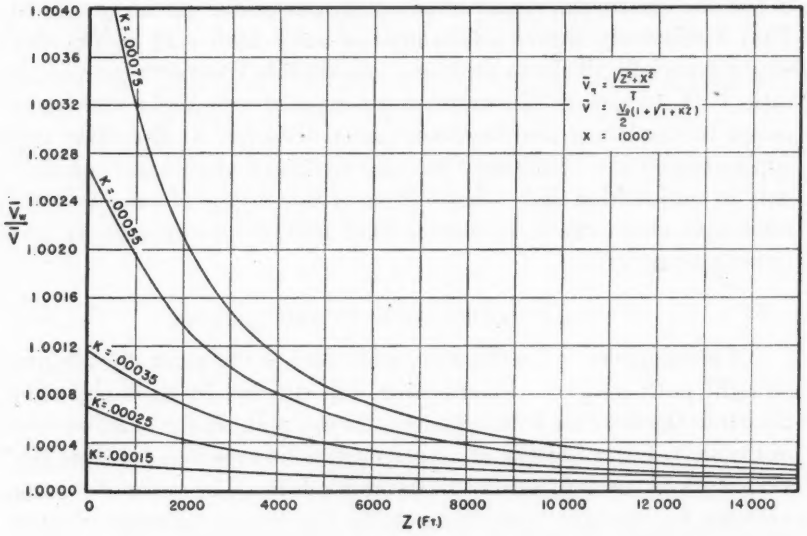


FIG. 2. Ratio of $\overline{V}_w$, average velocity given by straight path computation of well surveys, to $\overline{V}$, true average velocity, illustrated for velocities described by $V=V_0(1+KZ)^{1/2}$.

wave representations. In this scheme depth is expressed as

$$Z = \tfrac{1}{2}\cdot\overline{V}\cdot T_0\cdot\cos\theta \tag{9}$$

and horizontal projection of the path, or offset, as

$$Y = \tfrac{1}{2}\cdot\overline{V}\cdot T_0\cdot\sin\theta, \tag{10}$$

where $\overline{V}$ represents average velocity, T_0 denotes reflection arrival time at point of shot, and the parameter

$$\theta = \sin^{-1}(\Delta T\cdot\overline{V}/X). \tag{11}$$

ΔT in turn represents reflection time difference observed between opposite ends of a seismometer spread X symmetrically arranged about the shot point. This particular system was chosen because with its distinctive method of determining the angle of dip it comprises a fairly close approximation to curved path results without involving complex computations.

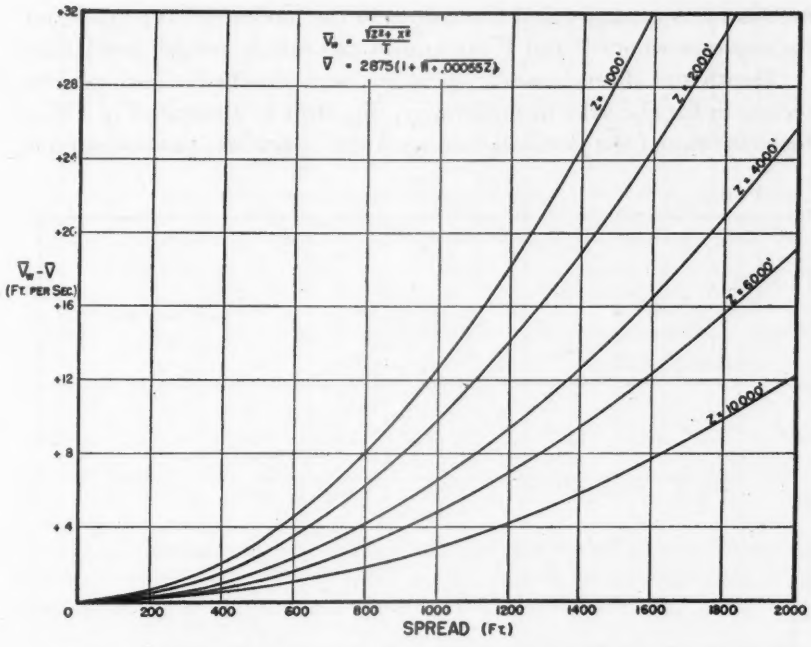


FIG. 3. Discrepancy between curved path and usual straight path well velocity computations, expressed as a function of shot-to-well distance for various depths for the particular velocity $V=5750(1+.00055Z)^{1/2}$.

DIP VARIANCE BETWEEN STRAIGHT PATH AND CURVED PATH COMPUTATIONS

If S represents slope of the waves as depicted, it can be shown that for any velocity function continuous to the point of reflection and dependent upon depth alone,

$$S = \sin\theta \cdot \cos\theta/(\sin^2\theta - \bar{V}/V). \tag{12}$$

Furthermore, if one considers central emergence angle to be correctly represented by

$$\phi_0 = \sin^{-1}(\Delta T \cdot V_0/X) \tag{13}$$

then application of Snell's Law leads to

$$\sin\phi = (V/V_0)\sin\phi_0, \tag{14}$$

and dip in turn corresponds to $\tan\phi$. A comparison can then be drawn

between this quantity and wave slope of the modified wave-ray chart for any case where V and $\overline{V}$ are known and satisfy proper conditions.

Depth and offset, however, have not been obtained in such general terms, so for the sake of uniformity, dip error is illustrated in Fig. 5 for velocities of the parabola family. A dip of 500 feet per thousand is

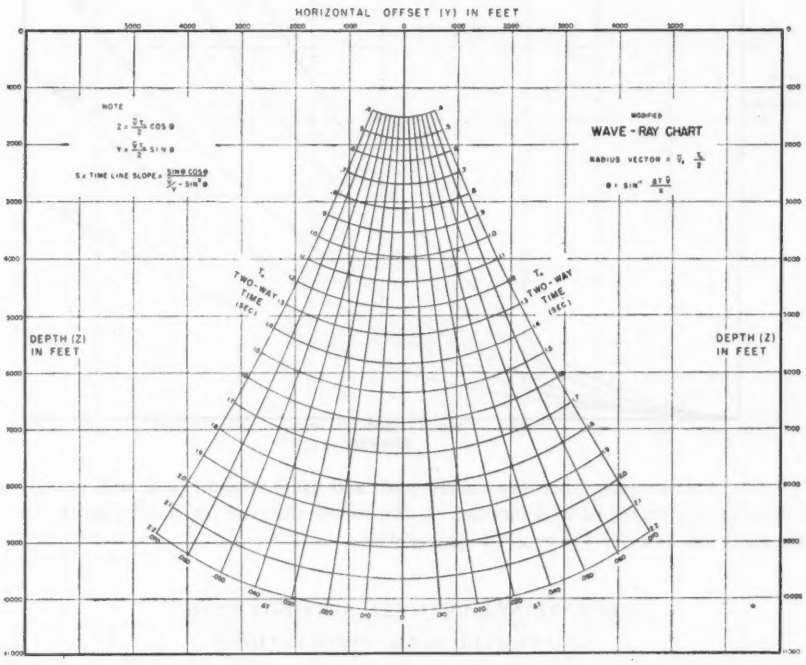


FIG. 4. Specific illustration of adopted straight path procedure. $\overline{V}$ is average velocity dependent on depth alone, T_0 is zero spread reflection time, and ΔT is reflection time difference between ends of symmetrically arranged seismometer spread of length X.

used to exaggerate the effect beyond the range commonly encountered in seismic prospecting.

By way of explanation: Each K line of the dip discrepancy chart was obtained by selecting appropriate values of ϕ_0, then solving Eqs. 5, 3 and 4, for $V_0 T_0$, as well as Y and Z. From these computed values of offset and depth the determination of θ is possible within practical limits by successive approximations to the end that dip variance can be evaluated. By superposing a graph showing $V_0 T_0$ in terms of T_0 for various initial velocities upon the graph of dip variance, the same type of progressive relation is embodied in Fig. 5 as in Fig. 1.

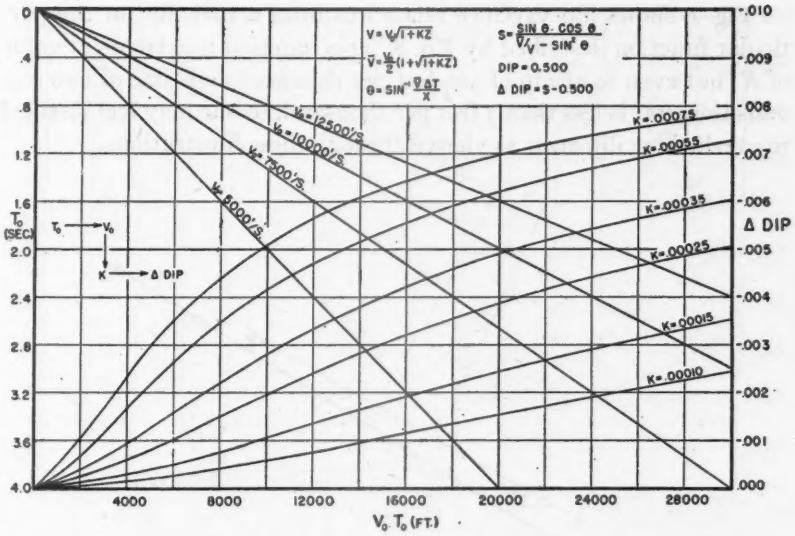


FIG. 5. Discrepancy between "straight path dip" and "curved path dip," where the former corresponds to "wave front slope" of Fig. 4. The illustration applies specifically to parabolic expressions for velocity and the rather extreme dip of 0.5.

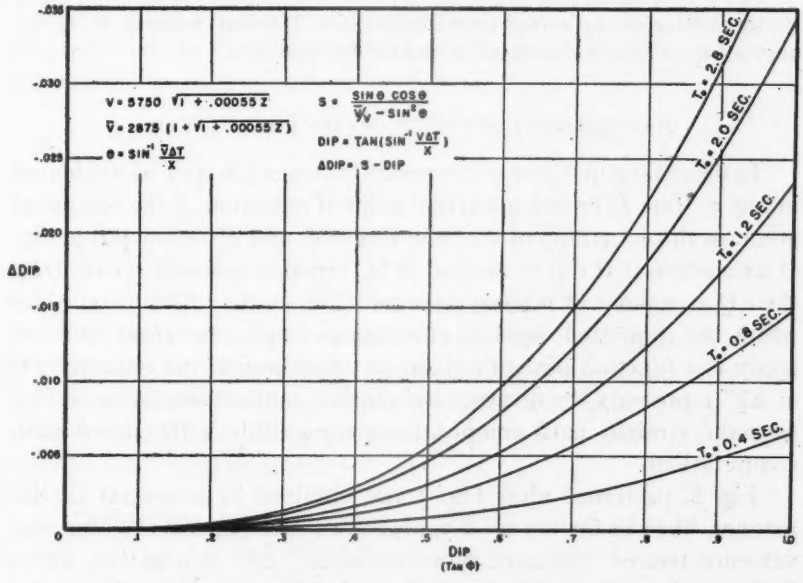

V = 5750 √1 + .00055 Z
V̄ = 2875 (1 + √1 + .00055 Z)
θ = SIN⁻¹ V̄ΔT/X
S = SIN θ COS θ / V̄/V − SIN² θ
DIP = TAN(SIN⁻¹ VΔT/X)
ΔDIP = S − DIP
T0 = 2.8 SEC.
T0 = 2.0 SEC.
T0 = 1.2 SEC.
T0 = 0.8 SEC.
T0 = 0.4 SEC.
ΔDIP
DIP (TAN Φ)

FIG. 6. Dip discrepancy for a specific velocity function, expressed in terms of dip for several reflection arrival times. *S* is "wave front slope" of the type chart illustrated in Fig. 4.

Fig. 6 shows dip variance related to total actual dip for the particular function described by Eq. 8. This function is extreme in value of K, but even so at dip of 500 feet per thousand and time of two seconds the error is less than 5 feet per thousand, so one may feel justified in overlooking dip error as viewed through these illustrations.

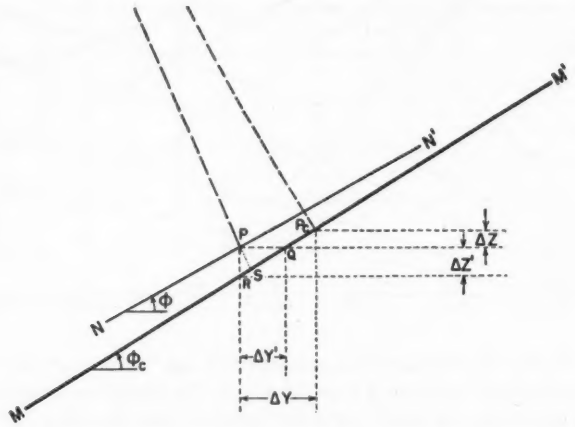


FIG. 7. P represents reflecting point computed by the modified procedure of Fig. 4. P_c, the point given by curved path computations. Different measures of the discaepancy are indicated; of these $\Delta Y'$ is used in following figures.

DISAGREEMENT BETWEEN OFFSET COMPUTATIONS

In describing distance errors several courses are open as evidenced in Fig. 7. Here P_c represents actual point of reflection, P the computed point, ϕ_c the actual dip of the reflecting bed, and ϕ the computed dip. If we assume that dip of the bed MM' remains unchanged over QP_c, then Q is a point of interest because it lies at the offset distance for which the computed depth is effective so long as we grant that velocity is a function of depth alone. In other words, the quantity PQ or $\Delta Y'$ represents the distance by which a contour should be shifted to make straight path computations compatible with curved path computations.

Fig. 8, patterned after Fig. 5 and obtained in somewhat similar manner, likewise for $\tan \phi = 0.5$, illustrates this quantity PQ, for convenience termed "adjusted offset variance." $\Delta Y'$ is negative, which indicates that offset given by the modified wave-ray chart is consistently less than that given by curved path procedure.

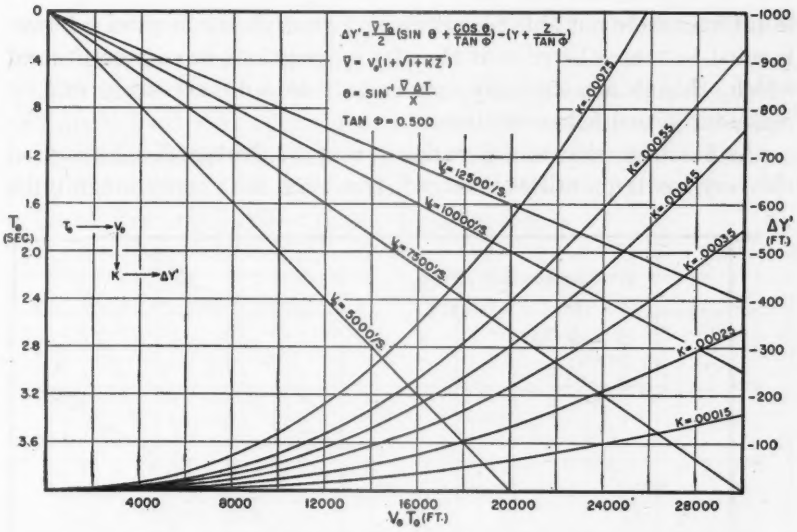


FIG. 8. "Adjusted offset variance," $\Delta Y'$ as described in Fig. 7, related to travel time for a dip of 0.5 and velocities of the type $V = V_0(1+KZ)^{1/2}$.

For a fairly typical velocity function, as described by Eq. 7 for instance, one has the following related values for a dip of 500 feet per thousand:

T_0	Adjusted Offset Variance	Offset
1.0	10 feet	1475 feet
1.5	25 "	2275 "
2.0	55 "	3225 "
2.5	95 "	4200 "

To show "adjusted offset variance" in another phase, though again for the rather extreme specific function of Eq. 8, a graph is provided in Fig. 9 wherein the discrepancy is plotted with respect to dip for selected travel times. This illustration and Fig. 8 show that offset variance can be appreciable.

DISCREPANCIES EVALUATED IN TERMS OF SOME LIKELY FIELD CONDITIONS

Before accepting the foregoing demonstrations at face value several important factors need to be taken into account which the author

is unfortunately not able to express in a general way in precise terms. It must be remembered that thus far assumptions have been utilized which, though academically convenient, do not necessarily exactly represent actual field conditions.

As has been shown, dip variance may be disregarded because of the very small quantities involved. However, the greater magnitudes

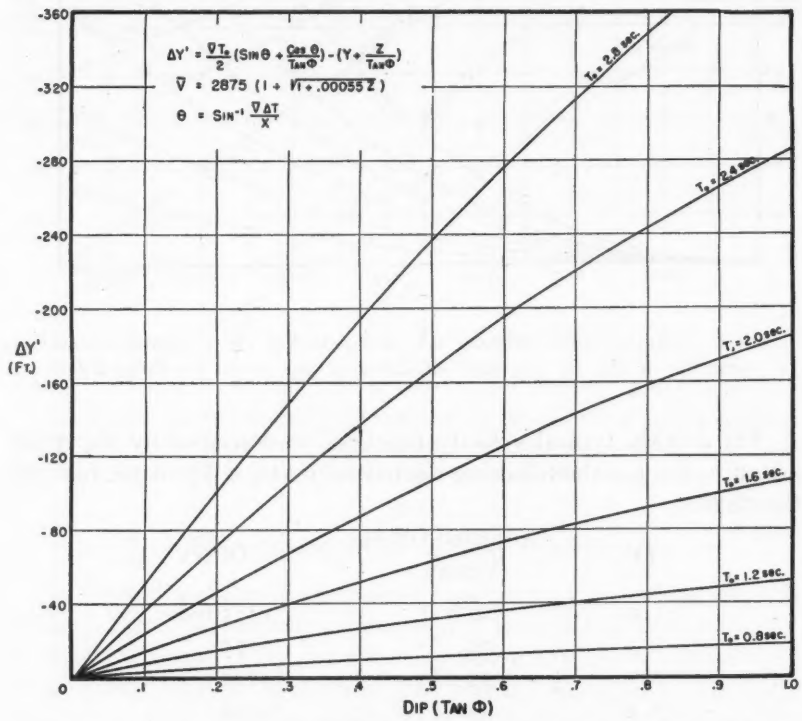


FIG. 9. "Adjusted offset variance," $\Delta Y'$ as defined in Fig. 7, expressed for listed reflection times in terms of dip. $V = 5750(1 + .00055Z)^{1/2}$.

of offset discrepancies coupled with the greater importance of obtaining the correct offset, deserve attention. At the same time the relation of these magnitudes to observational limitations and other factors needs to be recognized.

One important source of observational error lies in the determination of the reflection arrival time difference across a symmetrically arranged spread. Thus, if one considers an average velocity of 10,000 feet per second, and a reflection time of 2 seconds, then for a timing

error of .001 second across 1000 feet there results a total unadjusted offset discrepancy of about 100 feet.

Furthermore, well velocity surveys or derived results are of necessity applied often at appreciable distances from their origin. Curved path refinements easily can fade into insignificance by comparison with the changes that may occur in the velocity pattern between point of measurement and point of application.

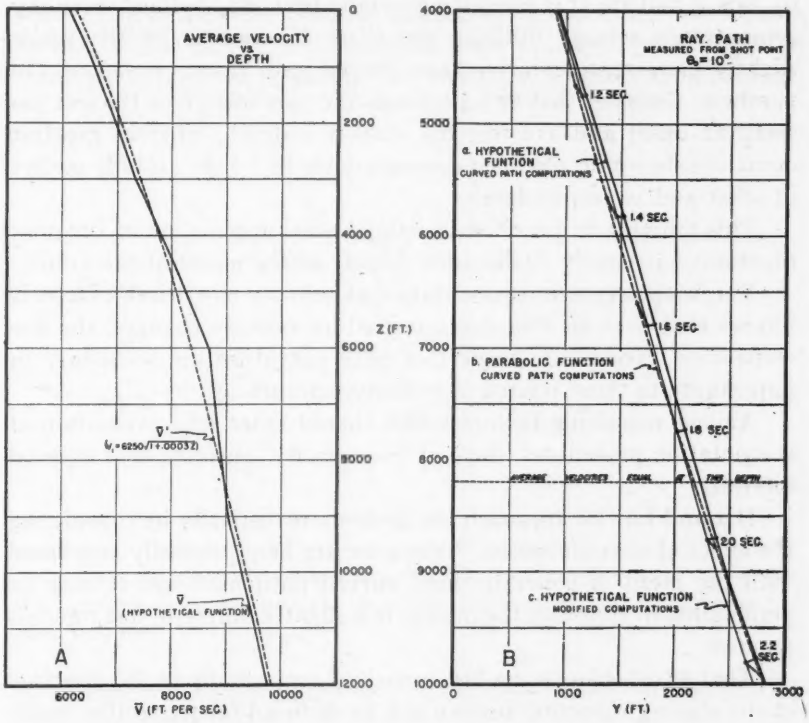


FIG. 10 A. Hypothetical irregular velocity approximated by parabola, illustrated in terms of corresponding average velocities. B. Selected ray computed by (a) hypothetical function, curved path method; (b) parabola, curved path method; (c) hypothetical function, modified procedure.

By way of a conservative estimate of the inaccuracies involved one might make use of a more appraisable situation. In Fig. 10A consider the irregular hypothetical average velocity function $\overline{V}$ to represent an actual velocity survey. Then let $\overline{V}'$ represent an attempt to fit the hypothetical function with a velocity formula:

$$V = 6250\,(1 + 0.0003Z)^{1/2}. \qquad (7)$$

Though irregularity of the assumed function may appear excessively large, a special effort was made to produce an example which typifies actual attempts at approximating velocity functions by parabolas. Fig. 10B illustrates ray paths corresponding to the hypothetical velocity function and its parabolic approximation. Alongside the hypothetical ray there is also shown the corresponding modified ray path given by Eqs. 9 and 10. It is interesting to note that the modified wave-ray computation scheme utilizing the exact function is on the whole slightly more representative than curved path results based on the parabola. Consider that at 1.4 seconds the parabola gives 180 feet too small an offset and 210 feet too shallow a depth, whereas greatest deviation shown for modified computations, at 2.2 sec., is only 90 feet in offset and 40 feet in depth.

This example is not cited to uphold areal application of irregular functions but merely to illustrate fidelity of the modified procedure.

Yet, with accurate representation of velocity so critical a factor it follows that over an area characterized by velocity changes, the discrepancies traceable to neglect of path curvature are secondary in importance to those related to velocity inaccuracies.

Among remaining factors which should enter into evaluation of computation procedures, slope of "iso-velocity" surfaces is of especial interest.

Dix and Lawlor approach the problem realistically by considering the effect of unconformities.[10] Since we are here primarily concerned with the merit of generally used curved path methods, it may be permissible to approach the matter in a slightly different, less rigorous manner.

That offset is less when "iso-velocity" surfaces dip in the direction of the sloping reflecting surface can be deduced for particular conditions from the following simple demonstration. In accordance with Snell's Law

$$V_2 \cdot \sin(\theta_1 - \alpha) = V_1 \cdot \sin(\theta - \alpha) \qquad (15)$$

in Fig. 11, which represents a ray PQ impinging at an angle θ_1 with the vertical upon a velocity interface which forms the angle α with the horizontal. The derivative,

[10] Dix, C. H., and Lawlor, R. E., *Computation of Seismic Dips Below an Unconformity*, GEOPHYSICS, Vol. VIII, No. 2, pp. 105–118 (April 1943).

$$d\theta/d\alpha = 1 - V_2 \cdot \cos(\theta_1 - \alpha)/V_1 \cdot \cos(\theta - \alpha), \qquad (16)$$

shows that if $V_2 > V_1$, $d\theta/d\alpha$ is negative. The horizontal projection of the lower ray segment OQ is $OQ \sin \theta$, which decreases as MM' is tilted in the direction of θ_1. The suggested reasoning can be applied in step-by-step fashion to a comparison of two series of velocity layers with velocities held constant within individual elements. One series may be assumed to have horizontal interfaces and the other, interfaces which slope in the same direction as a reflecting bed. If the two layouts are designed so that for some common central ray emergence angle the travel paths comprise equal distance elements in corresponding layers,

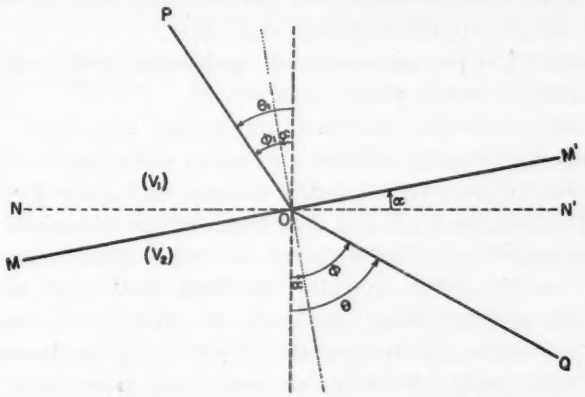


FIG. 11. A ray PO is presumed to strike MM' at an angle θ_1 with the vertical. MM', making an angle α with the horizontal, represents the interface between two velocity layers.

total offset will be less in the case of sloping velocity interfaces than in the horizontal case.

To the extent that this comparison can be relied upon, the less extreme modified computation procedure stands in better grace than curved path procedure, so long as neither specifically allows for probable slope of "iso-velocity" surfaces.

There is clearly a need for adjusting the velocity function to fit change in conditions as one covers certain areas. As far as the author knows, the straight path computation procedure described herein has a distinct advantage over curved path methods because of its direct relation to the vertical travel time computation scheme described

by Gaby.[11] By his method the conduct of computations enables one conveniently to reassign velocity scales for the express purpose of maintaining agreement between seismic interpretations and velocity revisions.

CONCLUSIONS

Any seismic velocity measurement based on reflection time differences which does not take into account curvature of ray path is in error to an extent dependent upon the increase of velocity with depth. Straight path computations yield velocities which are too high by amounts up to two per cent or more. On the other hand any attempt to allow for curvature should be preceded by a quantitative study of other irregular aspects of the problem, some of which may partially compensate for neglect of curvature.

Disregarding path curvature in connection with well velocity surveys involves merely trivial inaccuracies.

For the particular modified computing procedure described above, dip discrepancy relative to curved path results is likewise negligible; except for very steep dips coupled with a rapidly increasing velocity the discrepancy is less than eight feet per thousand.

Determination of offset involves somewhat greater discrepancies between "curved path" and the modified method of computing. Fortunately modified offset distances are consistently the smaller.

It is debatable whether usual curved path methods, wherein velocity varies only vertically, are any more dependable than the modified procedure. Should there exist a slight increase in velocity to any given depth as one follows a reflecting horizon upward, opposite from the direction of dip, such curved path procedure gives offsets and dips which are too great.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of Mrs. N. M. Hilger, who prepared the illustrations and aided with computations; also, sincere appreciation is felt for the criticisms and suggestions of C. H. Green, Phil P. Gaby, E. Thomas and others. Permission to publish this paper was kindly granted by Geophysical Service Inc.

[11] Gaby, *op. cit.*

RECENT DEVELOPMENTS IN GEOCHEMICAL PROSPECTING FOR PETROLEUM*

LEO HORVITZ†

ABSTRACT

A number of surveys completed during the past two years indicate that the geochemical prospecting technique can be applied successfully only when an area is explored which is sufficiently large to enable ready distinction of the anomaly from the background.

Geochemical anomalies found by reconnaissance sampling have been proved to be associated with structure by the reflection seismograph. These confirmations indicate that the two methods can be used to supplement one another; one to detect the possible presence of a petroleum accumulation and the other to determine the probable depth of the accumulation.

The results of a reconnaissance geochemical survey over the Heidelberg Area of Jasper County, Mississippi, are presented.

The most significant recent advance in geochemical prospecting has been the recognition that a relatively large region must be explored in order that the background, or normal, areas may be distinguished readily from the anomalous areas. In conducting surveys in this manner, the interpretation is greatly simplified.

During the past two years, several reasonably large reconnaissance surveys were conducted. One of these was over an area in Chambers County, Texas, covering some 20,000 acres. In all, 298 locations were sampled in this area using a relatively uniform grid of one sample to approximately 80 acres. The samples were collected at 12 feet and analyzed for methane and for ethane and heavier hydrocarbons.

The methods used in extracting the hydrocarbons from the soil samples and the subsequent analysis of the extracted gases have already been described in detail before the society on previous occasions. It will suffice here, therefore, to repeat that the hydrocarbons are removed from the soil in a partial vacuum and at temperatures below 100°C. to prevent decomposition of any organic matter that may be present. Acid is employed to release the hydrocarbons more efficiently. From 100 to 150 grams of sample are sufficient for the extraction procedure.

The extracted gases are passed through potassium hydroxide

* Read at the Houston and Dallas Meetings of the Society, 1945.

† Horvitz Research Laboratories, Houston, Texas.

solution, concentrated sulfuric acid and, finally, through phosphoric anhydride before separating them into two fractions, one containing the methane and the second containing the ethane and heavier hydrocarbons. This separation is effected under a high vacuum at a temperature of −196°C. At this temperature, methane is non-condensable while the ethane and heavier hydrocarbons are trapped out.

The quantity of methane present is calculated from the amount of carbon dioxide produced upon combustion over a hot platinum wire in the presence of pure air or oxygen. The ethane and heavier hydrocarbons are measured with a sensitive McLeod gauge and their presence confirmed by combustion over a hot platinum wire in the presence of pure air or oxygen. The analytical results are expressed in parts per billion by weight on the dry sample basis.

The results of the survey in Chambers County revealed the presence of only one significant geochemical anomaly which was readily apparent over a background of very low hydrocarbon concentrations. The ethane and heavier hydrocarbon values which outline the anomaly average 52 parts per billion as compared to an average of 5 parts per billion for the background, yielding a contrast of more than 10. Of the 20,000 acres sampled, the anomalous area covers about 1,000 acres. The methane data yielded a distribution pattern very similar to that of the ethane and heavier hydrocarbons, substantiating the finding that more and more importance must be attached to methane, excepting, of course, for those cases in which marshy areas are sampled.

After the geochemical work was completed, a reflection seismograph survey was made in the vicinity of the geochemical anomaly. The presence of structure was definitely indicated, but the center of the seismic anomaly was displaced from the center of the geochemical anomaly by approximately 2,000 feet.

Another area, comprising over 100,000 acres in the Texas Gulf Coast, was covered with a reconnaissance grid of one sample to approximately 80 acres. Three geochemical anomalies were found in this area. Over the most outstanding of these, a reflection seismograph survey was made. Definite evidence of structure, at a relatively shallow depth, was found and in this case the centers of the geophysical and geochemical anomalies coincided. Furthermore, both anomalies were approximately of the same areal extent. Neither of the anomalies referred to have, as yet, been tested by the drill. How-

ever, the results obtained indicate quite definitely that the geochemical technique can be used as a reconnaissance tool in advance of seismic methods.

In recommending the geochemical method for reconnaissance, it is not the writer's intention to suggest that only those anomalies that are confirmed by the reflection seismograph are significant. The possibility should be considered that an outstanding geochemical anomaly, *not* associated with structure, is reflecting a stratigraphic trap. Of course, in such a case, no advance knowledge concerning the possible depth of the accumulation can be obtained.

GEOCHEMICAL SURVEY OF THE HEIDELBERG OIL FIELD, JASPER COUNTY, MISSISSIPPI

Up to about a year ago, most of the geochemical work performed by this laboratory was in the Texas and Louisiana Gulf Coasts. With the discovery of the Heidelberg oil field, the petroleum industry's attention was focused upon Mississippi. It was considered of interest to obtain geochemical data in this new trend, and, therefore, an experimental survey was made in the Heidelberg area during the period from May 28, through July 28, 1944.

Figure 1 shows the results of a reconnaissance survey over the Heidelberg area, Jasper County, Mississippi. This survey consisted of the analysis of 364 samples collected at depths of 12 feet. The station locations together with the total hydrocarbon values (methane plus ethane and heavier hydrocarbons) are shown on the map. The field development at the time when the survey was started is shown by the well symbols. In order to ascertain the background values, data were obtained over an area extending four to six miles east, west, and south of the then known producing limits.

The following groups of values (expressed in parts per billion by weight) are enclosed by the various contour lines: 50–99; 100–199; 200–399; 400–799; 800 and above. In order to display the variations in hydrocarbon concentration over the area sampled, various degrees of shading have been used; the darker the shading, the higher the concentration. Values below 50 parts per billion by weight are in the unshaded areas; values from 50–99 parts per billion are in the areas with the lightest shading; values from 100–199 parts per billion are in the medium shaded areas, and values of 200 parts per billion and above are in the zones with the heaviest shading.

In view of the fact that a significant geochemical anomaly is one

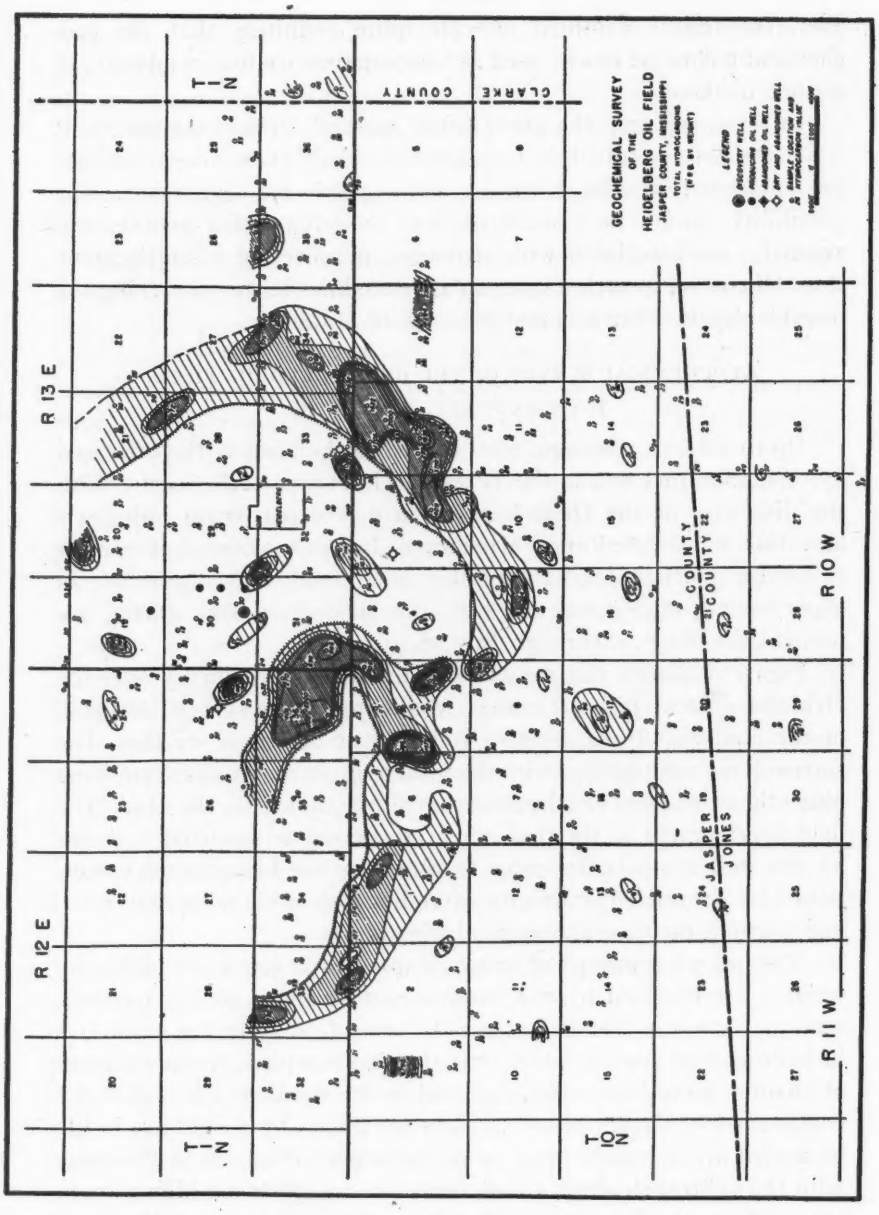


FIG. 1. Geochemical survey of the Heidelberg Area, Jasper County, Mississippi. Well symbols show field development at start of survey, May 28, 1944.

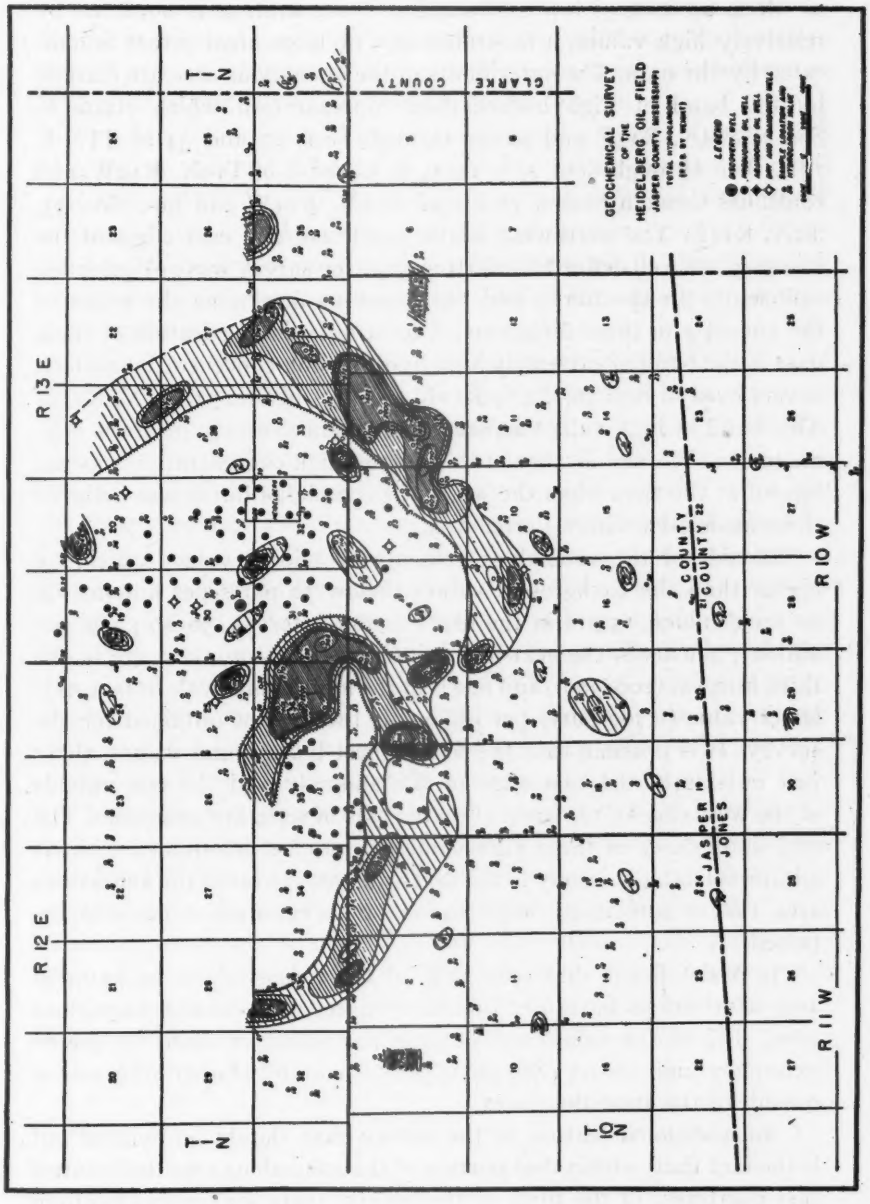


FIG. 2. Geochemical survey of the Heidelberg Area, Jasper County, Mississippi. Field development as of March 20, 1945 is indicated by well symbols.

in which an area of low hydrocarbon concentration is bordered by relatively high values, a favorable area of large areal extent is indicated by the data. The outer limits of the anomalous area are marked by the band of high hydrocarbon concentration which starts in Sec. 21, T1N, R13E and passes through Secs. 27 and 34 of T1N-R 13E, then through Secs. 2, 3, 10, 9, 8, 5, and 6 of T10N, R10W, and continues through Secs. 1 and 2 of T10N, R11W and into Sec. 33, T1N, R12E. The southwest, south, southeast, and east edges of the anomaly are well defined. Unfortunately, the survey was not extended sufficiently to the north and northwest to determine the edges of the anomaly in these directions. A most outstanding feature of these data is the band of extremely high hydrocarbon concentrations which covers most of Sec. 36, T1N, R12E and part of Sec. 31, T1N, R13E. This band of high values separates the main anomaly into two subanomalies. The significance of this area of high concentration was not known at the time when the work was completed but it was believed to be associated with a barren area.

Outside of the anomalous area are occasional values which are higher than the background values (below 50 parts per billion). Of 25 such values, 15 are in the first contour interval (50–99 parts per billion); five are in the next higher interval (100–199), four are in the third interval (200–399), and one is in the highest interval. In fact, this latter value (6,790 parts per billion) is the highest obtained for the survey. It is possible that the five highest background values, those just outside of the east edge of the anomaly and the one outside of the west edge of the anomaly, are parts of separate anomalies. The real significance of these high values cannot be determined without additional data. It is only to the south and southwest of the anomalous area that a sufficiently large region of background values was obtained.

It is significant that only 15% of the values in the background area attained 50 parts per billion or more, while in the anomalous area, 38% of the values are 50 parts per billion or more. Of the 16 extremely high values (800 parts per billion and above), only one is outside of the anomalous area.

An additional feature of the survey that should be pointed out is the fact that, within that portion of the anomalous area that centers just northwest of the town of Heidelberg, there are several localized groups of high hydrocarbon values, while within the secondary anomaly to the west, the approximate center of which is located to

the south of the center of Sec. 35, T1N, R12E, all values are considerably below 50 parts per billion. It is suggested that the localized groups of high values over the main Heidelberg field are associated with the complex faulting in that portion of the field.

It will be observed that a uniform grid was not used in conducting this survey. Instead, advantage was taken of the network of roads which covers the area, thus permitting the sampling of a large region within a relatively short period of time. A uniform grid would undoubtedly have produced a more outstanding pattern. This procedure could not be followed because of the limited time available for conducting this survey.

Figure 2 shows the development of the Heidelberg oil field as of March 20, 1945. It is apparent that the geochemical data predicted the development rather well. One of the most outstanding confirmations of the geochemical survey was made on February 21, 1945, when two wells were completed in Sec. 36, T1N, R12E, one in the southwest quarter and the other in the northwest quarter. The well in the southwest quarter was completed at 5,312–18 feet as the highest gravity oil well in the Heidelberg field, while the well in the northwest quarter crossed a fault and was abandoned as dry at a depth of 5,495 feet. Other interesting tests drilled since the geochemical work was completed include the well in Sec. 9, T10N, R10W which was abandoned as dry at a depth of 5,854 feet, and the well drilled in Sec. 21, T1N, R13E which was abandoned as dry at a depth of 7,370 feet. Production in the field is being obtained above 5,400 feet.

Although the attitude of the oil industry toward geochemical prospecting methods has become much more favorable than it has ever been in the past, resulting in an increase in use of this type of exploration, a sufficient number of geochemical anomalies has as yet not been tested by the drill to permit of a reliable statistical evaluation of the method. Data accumulated during the past few years are most encouraging however, and point to the eventual acceptance of the geochemical technique as an official member of that elite group of already established exploration methods.

AN INVESTIGATION OF NATURAL EARTH CURRENTS*

R. S. DAHLBERG, JR.†

ABSTRACT

An attempt was made to obtain relative apparent resistivities by measuring the potential gradients produced by natural earth currents. Alternating components in the range 0.5 to 10 cps. were measured.

The results of two surveys in Oklahoma are shown and various perturbing factors are discussed. The conclusion is reached that the method is not likely to replace conventional resistivity methods.

Natural earth currents have been a subject for investigation in geophysical laboratories for many years. These studies show that earth currents form great whorls on the face of the earth. The patterns maintain a fixed position with respect to the sun, and the rotation of the earth causes the currents at any one station to undergo periodic diurnal variations. In addition to the major diurnal variation, semi-diurnal and shorter period variations are recorded. In this latitude the preponderant direction of current flow is north-south.[1] These current patterns are on a vast scale so that over extended areas the directions of current flow should remain sensibly parallel in the absence of resistivity irregularities.[2] We might think of these currents as part of a gigantic restistivity spread with current electrodes effectively an infinite distance away. Schlumberger has investigated the possible use of these "telluric currents" to map the basement complex in Sumatra and outline salt domes in Alsace.

Using the concept of a vast resistivity spread, we cannot obtain ordinary resistivity data, since we do not know the current input. However, it should be possible to obtain relative resistivity data by comparing the potentials developed across two co-linear electrode intervals. Supposing that the same current flows under the two spreads, the potential drops should be proportional to the average apparent resistivities. This idea is illustrated in Fig. 1, where the two

* Presented at fifteenth annual meeting, Tulsa, Oklahoma, April, 1945, and Dallas sectional meeting, May 1945. Published with the permission of The Carter Oil Company, Tulsa, Oklahoma.

† The Carter Oil Company, Tulsa, Oklahoma.

[1] Physics of the Earth VIII, Chapter VI, Earth Currents, W. J. Rooney, p. 295.

[2] Marcel, Schlumberger, *The Application of Telluric Currents to Surface Prospecting*, Transactions of Am. Geoph. Union, 20th Annual Meeting, Part 3, p. 271, 1939.

spreads have one electrode in common. Having compared the potentials of intervals 1 and 2 we can move up one electrode interval and compare 2 and 3, then by multiplying the ratios measured we can refer interval 3 to interval 1. Neunschwander and Metcalf have reported work based on this scheme[3] in which they were able to show that the electrical noise voltages at relatively high frequencies were proportional to shallow resistivity as measured by conventional methods. They concluded that the method did not offer any advantage over conventional resistivity methods. Considering the skin effect at the frequencies used by Neunschwander and Metcalf (mostly above 100 cps.) and a table[4] of effective depth of current penetration vs. frequency given below; their results seem very reasonable.

f	ft.
0	inf.
1	3,300
4	1,650
100	825
1,000	83

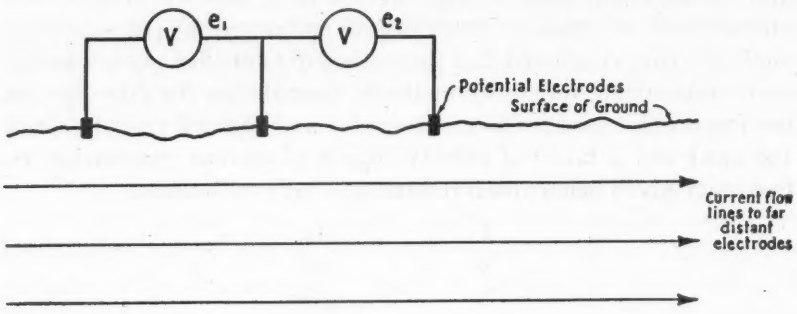
Schlumberger on the other hand used recording potentiometers and made his measurements on relatively long period variations (the most usual period was 20 seconds) so that his maps should have reflected the resistivity to great depths, or more probably the depth to the basement supposing that the resistivity contrast of the basement rocks was sufficient to confine the currents to the sediments above.

It seemed to us that it might be profitable to investigate the possible utility of measurements on the frequencies lying between 0.1 and 10 cps. In this range the effective depth of current penetration encompasses the depths of interest in oil prospecting and some control over the effective depth of the measurement could be had by utilizing components of various frequencies. Neunschwander and Metcalf reported that the electrical earth noise of frequency below 1000 cps. consisted principally of isolated impulses of random amplitude and were not amenable to accurate measurement with the null balancing method which they were using. For that reason we determined to record the noise voltages so as to be able to take measurements on individual pulses.

[3] E. F. Neunschwander and D. F. Metcalf, *A Study of Electrical Earth Noise*, GEOPHYSICS, Vol. VII, 1 (Jan. 1942), pp. 69–77.

[4] J. J. Jakosky, Exploration Geophysics, p. 394.

After determining that there were earth potential variations of a few hundred microvolts per mile in the frequency range from 0.1 to 10 cps. two resistance capacity coupled amplifiers were built which had a very low noise level and adjustable broadly tuned filtering. At a later time these were supplemented with a pair of sharply tuned



$$e_1 \propto I r_1 \qquad e_2 \propto I r_2$$

$$\therefore \frac{e_1}{e_2} = \frac{r_1}{r_2}$$

Also $e_3 \propto I r_3$

and $\frac{e_2}{e_3} = \frac{r_2}{r_3}$

$$\therefore \frac{e_1}{e_2} \times \frac{e_2}{e_3} = \frac{r_1}{r_2} \times \frac{r_2}{r_3}$$

and $\frac{r_1}{r_3} = \frac{e_1}{e_3}$

FIG. 1. Principle of natural earth current potential gradient measurements and relation of voltage ratios to resistance ratios.

but non-adjustable amplifiers with a peak response at 1.5 cps. These amplifiers were used to drive galvanometers in a reflection seismograph camera with the paper speed much reduced. Precautions were taken to have the input impedance of the amplifier high so that electrode contact resistance was negligible. The galvanometers were poled so that if the earth currents under the two spreads were flowing in the same direction, the galvanometers deflected in like directions. It proved inconvenient to calibrate the amplifier gain on each set-up,

and instead the records were taken in two sections, exchanging the inputs to the amplifiers between sections. From measurements on the two sections, voltage ratios can be derived without knowing the relative gains of the amplifiers, as indicated in Fig. 1.

The records obtained can be divided into three general classes:

A. In which the traces line up, and move in the same direction at the same time, i.e., the tracking is good.

B. In which the traces line up, but move in opposite directions—i.e., one trace is inverted to the other as if current flow in the ground were toward or away from the center electrode.

C. Random records in which the traces do not seem related to each other.

Type C records are rare. Type B records were observed in the vicinity of pipelines. In general, no record belongs exclusively in any one class. Sections of actual records obtained are reproduced in Fig. 2.

It has been found that, even on good records where the tracking is excellent, measurements of kicks on different parts of the same record do not yield the same ratio within the errors of measurement. This could be caused by curvature of the current paths, or by random voltages superimposed on the desired voltages, by variations of the ratio with frequency, etc. To minimize errors, a statistical average was taken utilizing as many of the best tracking impulses on the record as possible.

On the assumption that the potential gradient ratio evaluated can be referred to the midpoint of the interval for which it was determined, loops were run by straddling the corners with an electrode interval in each of two directions.

RESULTS

The Seneca fault system near Pryor, Okla., was surveyed with two profiles north and south and one tie line east and west which was extended to cross the structure. The area and stations are mapped in Fig. 3. The space between the two faults is a down-thrown block, the throw being estimated at 100 to 200 feet. Fig. 4 shows a profile which had been surveyed three years before by a shallow D.C. restistivity crew. The earth potential and resistivity data check nicely. The D.C. resistivity curve shows the graben as a restistivity low and indicates that it is wider to the north than shown by the geological map from which the fault lines were sketched. The faults are not easily observable on the surface at this place. The peaks shown

by the earth potential data on each side of the low are to be expected; telluric currents tending to concentrate in the low will increase the current density in the vicinity giving rise to an anticipatory increase in the earth potential gradient.

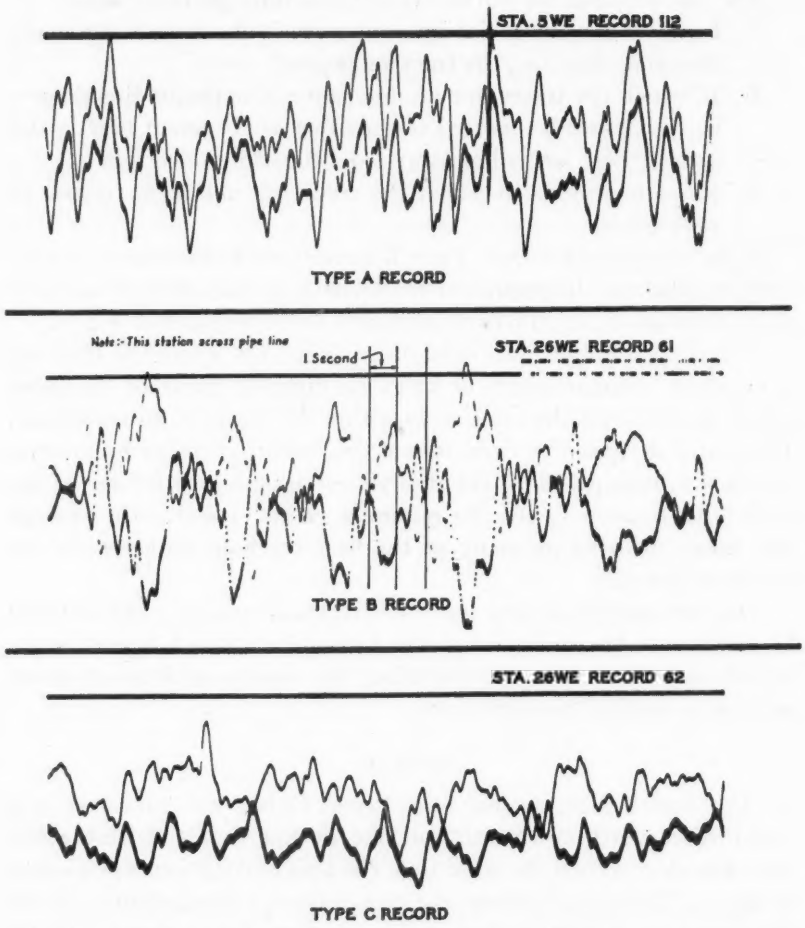


FIG. 2. Examples of the three different type records observed.

The profile in Fig. 5 does not show the fault as clearly as that of Fig. 4. The east-west profile in Fig. 6 is considered unreliable. The records were very poor along this line and the potential gradients much smaller than north-south. Fragmentary evidence indicates that in this area currents are strongly restricted to an almost due north-

south direction. Along the north-south lines the records were of generally good quality and the potential gradients were the largest observed in any area, reaching a value of around three millivolts per

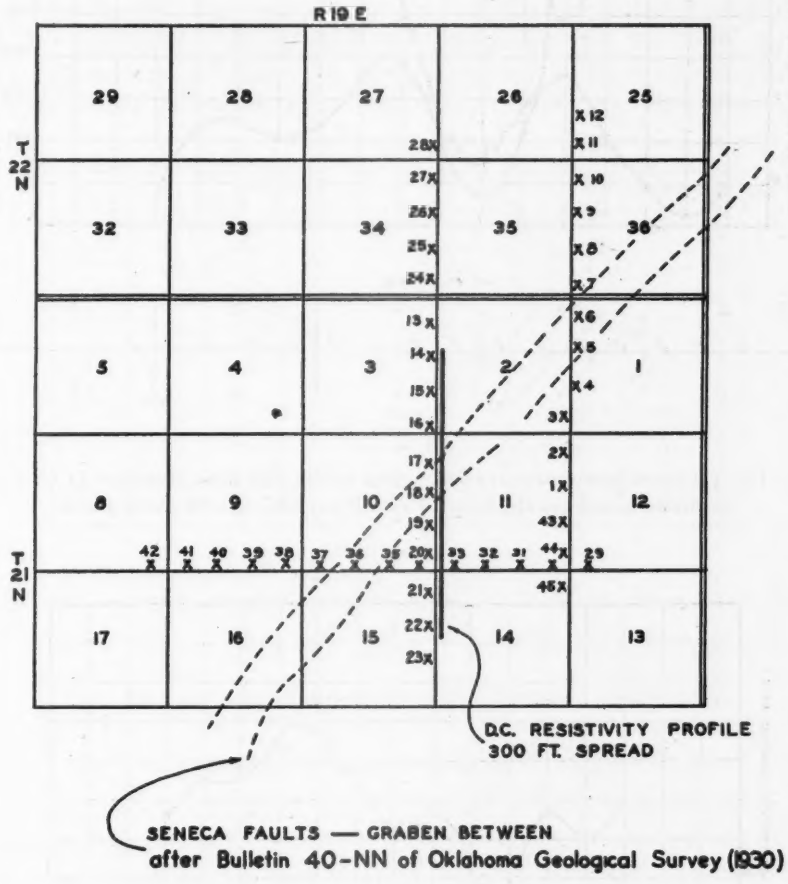


FIG. 3. Observation stations, region of Seneca Fault system, near Pryor, Okla.

mile. The data derived from different frequencies were similar and only one set of data is plotted.

Another survey was made over the Fitts and Stonewall faults east of Stonewall, Oklahoma. This area was characterized by vanishingly small potential gradients—particularly at the lower frequencies. Because of this it was not always possible to get usable records, and

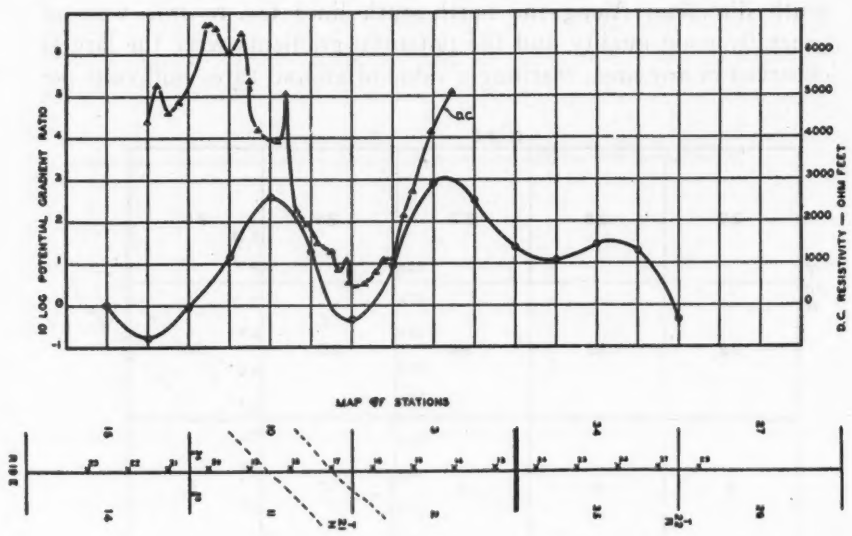


FIG. 4

FIG. 4. Comparison of natural earth current results with those of shallow D. C. resistivity measurements, Seneca Fault, Pryor, Okla., north-south profile.

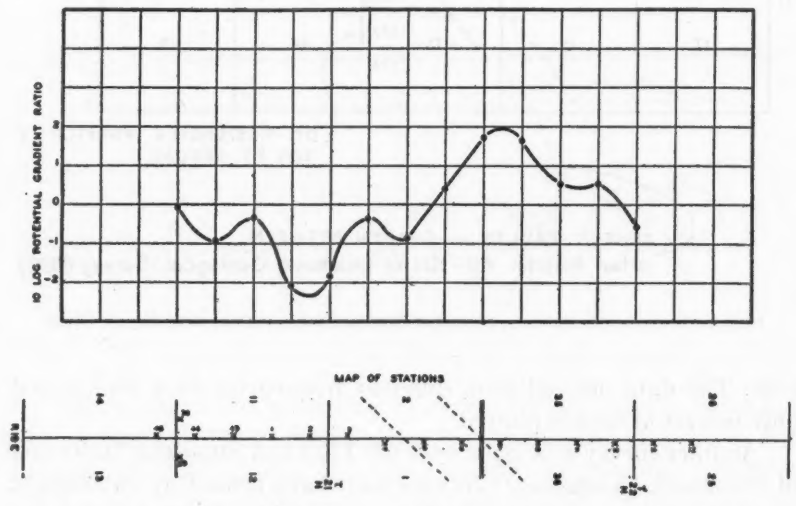


FIG. 5. North-south natural earth current profile, Seneca Fault, Pryor, Okla.

curves were completed only for the sharply peaked amplifiers at 1.5 cps. and for the broadly peaked amplifiers recording mostly around 10 cps. For a map and the plotted data see Figs. 7, 8, 9, and 10. Eltran data obtained several years before were available on the profile shown in Fig. 8, and they are plotted for comparison. The earth potential gradient data do not show anomalies over the faults, but the Eltran data do indicate the surface traces. Also the earth potential data are not self-consistent as is shown by the failure to tie in Fig. 10.

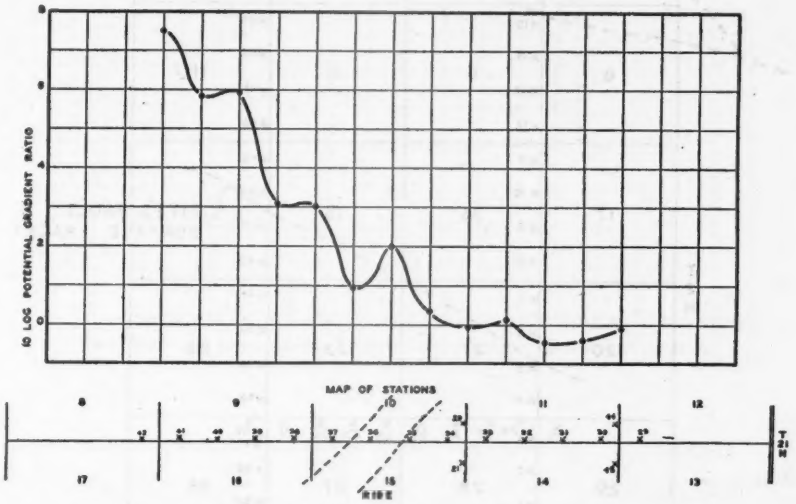


FIG. 6. East-west natural earth current profile, Seneca Fault, Pryor, Okla.

INVESTIGATIONS INTO SOURCES OF ERROR

Interfering voltages are always present, even on the best records, and attempts have been made to identify the sources. Seismis electric voltages of local origin have been noted—particularly in the course of some work in Louisiana where, on certain setups, passing traffic, or even movements within the recording truck, created large fluctuating potentials in the electrode lines. This was apparently connected with the presence of sand beds. These voltages were absent or very small where the surface material was mostly clay and rock. Other local sources of current have been sought, but in the area traversed (near Tulsa) no natural sources have been found. A railroad, however, did show up as a noise high.

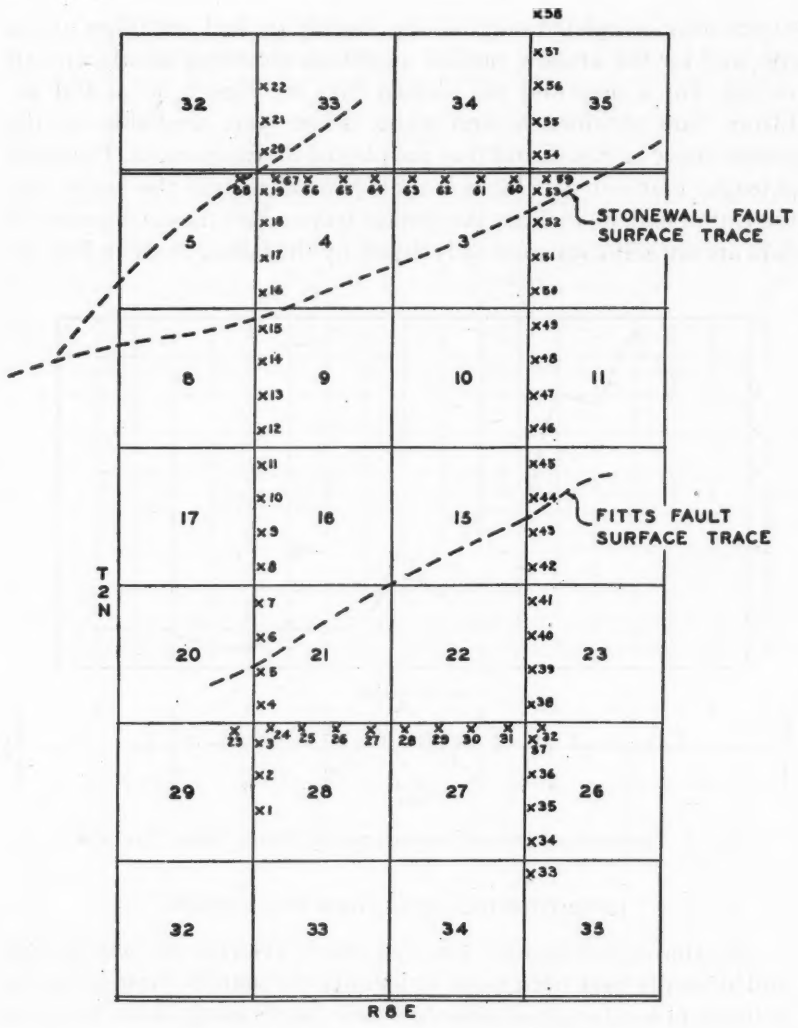


FIG. 7. Observation stations, region of Stonewall and Fitts faults, Pontotoc Co., Okla.

Other possible sources of local interfering noise voltages have been investigated; one was electrode noise, or the possibility of spontaneous changes in the contact potential at the electrode. This may be a factor at times, perhaps it is the mechanism of the seismic-electric effect noted above, but measurements on the total voltage developed

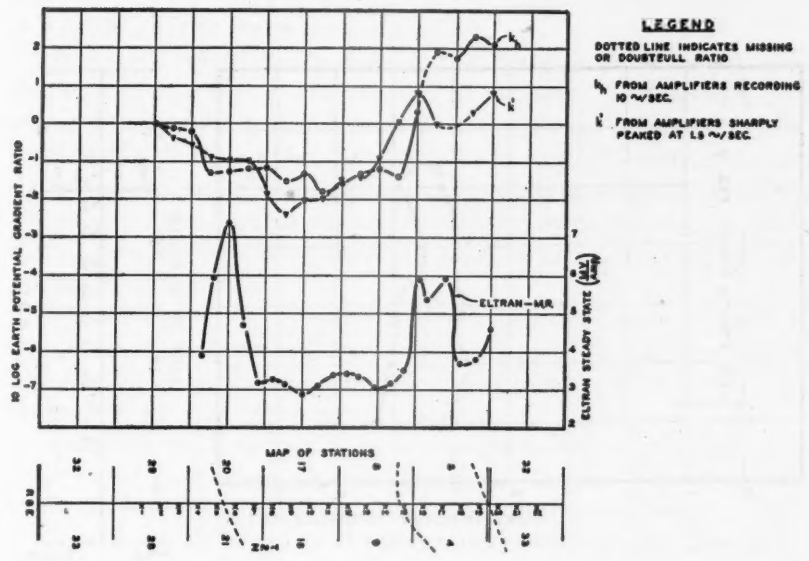

LEGEND
DOTTED LINE INDICATES MISSING OR DOUBTFULL RATIO
FROM AMPLIFIERS RECORDING 10 ~/SEC.
FROM AMPLIFIERS SHARPLY PEAKED AT 1.5 ~/SEC.
10 LOG EARTH POTENTIAL GRADIENT RATIO
ELTRAN STEADY STATE (MV/KM)
ELTRAN—MR
MAP OF STATIONS

FIG. 8. Comparison of natural earth current results with those of Eltran survey, Stonewall and Fitts faults, Pontotoc Co., Okla.; north-south profile.

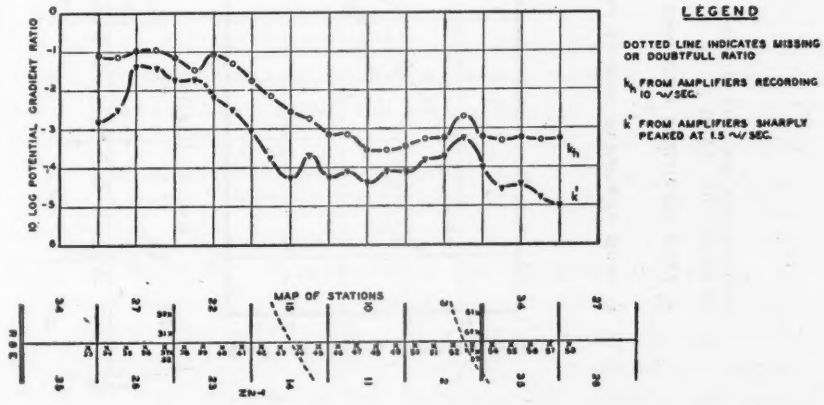

LEGEND
DOTTED LINE INDICATES MISSING OR DOUBTFULL RATIO
FROM AMPLIFIERS RECORDING 10 ~/SEC.
FROM AMPLIFIERS SHARPLY PEAKED AT 1.5 ~/SEC.
10 LOG POTENTIAL GRADIENT RATIO
MAP OF STATIONS

FIG. 9. Comparison of natural earth current results with broadly peaked amplifiers (10/sec.) and sharply peaked amplifiers (1.5/sec.); Stonewall and Fitts faults, Pontotoc Co., Okla. (North-south profile.)

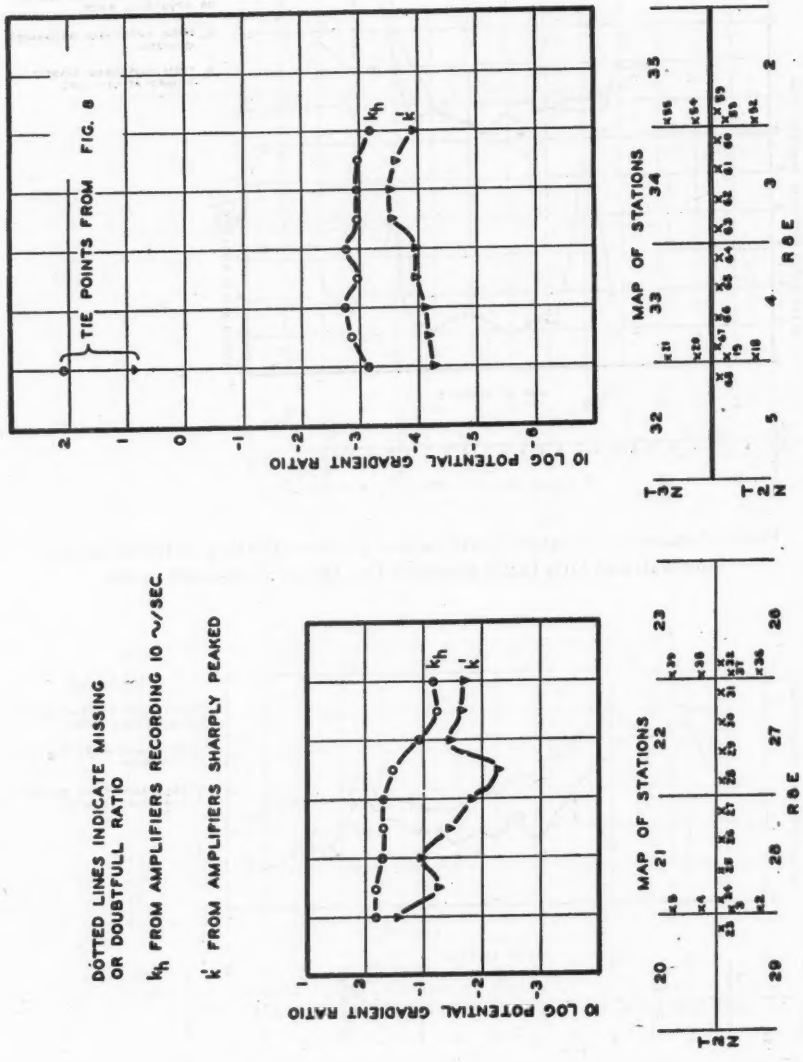

TIE POINTS FROM FIG. 8
10 LOG POTENTIAL GRADIENT RATIO
MAP OF STATIONS
DOTTED LINES INDICATE MISSING OR DOUBTFULL RATIO
k_h FROM AMPLIFIERS RECORDING 10 ~/SEC.
k' FROM AMPLIFIERS SHARPLY PEAKED
10 LOG POTENTIAL GRADIENT RATIO
MAP OF STATIONS

FIG. 10. Same as Fig. 9, but for two east-west profiles.

between two electrodes close together (20 ft. separation) showed that it is a negligible quantity most of the time.

It seemed reasonable to suppose that some of the noise voltages might arise as a kind of loose contact phenomenon between particles of earth analogous to the hiss of a carbon button microphone, the current flow producing the noise being the known D.C. earth currents. To test this hypothesis, records were taken while passing D.C. through the ground from current electrodes placed outside the regular electrode spread. The current flow had no detectable influence on the voltage recorded.

Remembering the seismic-electric phenomena noted, it seemed that some of the recorded noise could be caused by seismic ground unrest, but no correlation could be observed with either vertical or horizonatal ground unrest near Tulsa.

An air-to-earth current is known to exist, and an attempt was made to correlate the voltages between two electrodes with variations in the atmospheric potential gradient, but this was negative.

Among the sources of error which must be considered is the effect of current path curvature. Presumably, we are dealing with currents coming from long distances, and since the effective depth of current penetration is a few thousand feet, the average apparent resistivity of the large bulk of earth with which we are dealing should change slowly, and current path curvature should be small. It is not easily susceptible to measurement and no numerical figure can be given. It can be seen, however, that if the telluric currents flow preponderantly in one particular direction, records made with the electrode spread at right angles to that direction will be greatly influenced by even small amounts of current path curvature. A few estimates of the directions of the voltage impulses recorded have shown that the most and the largest pulses in the vicinity of Tulsa have a direction slightly west of north. This direction agrees roughly with hodographs of the earth potential variations as recorded by the magnetic observatory at Tucson, Arizona.[5] If the potential gradients studied here are attributed to the same general causative agents which are responsible for the longer period earth currents observed by geophysical observatories, it is to be expected that in the middle latitudes the most reliable data will be derived from profiles that extend generally north-south and this is borne out by the surveys reported above.

[5] J. A. Fleming, Terrestrial Magnetism and Electricity, p. 294.

CONCLUSIONS

Positive correlation between earth potential gradient curves and apparent resistivity has been obtained in the Seneca fault region. Geologically, the Seneca fault region is exceptionally favorable. The basement rock complex is near the surface (outcropping at one point nearby) and with the usual high resistivity associated with igneous rocks as compared to the overlying sediments, the current penetration is probably quite limited, which leads to a high current density in the upper strata and large, easily measured potential gradients. This is, of course, precisely the type area in which conventional resistivity methods operate best but even here east-west potential gradient profiles were unsatisfactory. Conventional resistivity methods have the advantage of absolute instead of relative measurement, and of being able to operate in any direction.

In other areas, correlation with either geologic conditions or electrical data from other methods is fair to non-existent. The chief reason for lack of correlation would seem to lie in the relatively small signal-to-noise ratio which is obtained even for electrode intervals as great as $\frac{1}{2}$ mile.

TORSION BALANCE STEP ANOMALIES IN NORTHERN TILLMAN COUNTY, OKLAHOMA

K. KLAUS

ABSTRACT

The results of a semi-detailed areal torsion balance survey in Southwestern Oklahoma are shown by means of a gradient-curvature map, a gravity map, two second derivative contour maps, and gravity and second derivative profiles. Detailed quantitative calculations were made of a number of geological cross sections, two of which are shown in Figs. 8 and 9. Fig. 9 represents the subsurface situation with the highest probability rating, since it combines a high degree of geological probability with the fact that it will reproduce the gravity and second derivative curves of Figs. 6 and 7 very closely. This interpretation embodies a fault with a throw of the order of magnitude of 10,000 feet.

If this interpretation is substantially correct, it implies a thick sedimentary section in the down-thrown block, which might be of great economic interest in prospecting for oil. A comparison of the gravity and second derivative data may be of interest to the geophysicist. The geologist may find the results of this survey interesting because of their possible bearing on the orogeny of the Wichita Mountains.

INTRODUCTION

During the summer of 1943, a semi-detailed areal survey was made in the southwestern rim of the Wichita Mountains, in northern Tillman and southern Kiowa Counties, Oklahoma (Fig. 1). This area was suspected of faulting from some previous work, and the present survey contains two step anomalies which are interpreted as associated with a large subsurface fault, with an indicated throw of the order of 10,000 feet. Although similar faulting is known from the southwestern flank of the related Amarillo Uplift, and the southwestern flanks of the probably related Criner Hills and Muenster Arch, faulting of the southwestern flank of the Wichita Uplift has not been previously reported, as far as the writer knows, and might be of general interest.

GRADIENT-CURVATURE MAP

We observed 134 torsion balance stations in this area, all but 10 of which (in the extreme southwestern edge of the survey) are shown in fig. 2. Large type photographically registering Askania balances were used for this work. More than half of the observations were made at night, with observation periods ranging from 11 to 16 hours. The minimum observation period for day stations was 7 hours. The stations were spaced approximately 0.7 miles apart, with a station at

every half-mile corner, with the exception of the base line separating T 1N from T 1S, where stations were spaced approximately half a mile apart. The results were plotted in the conventional manner at a scale of 1mm. per Eötvös Unit.

The prominent NW-SE striking zone of large north-easterly gradients in the central portion of the map, and the abrupt change

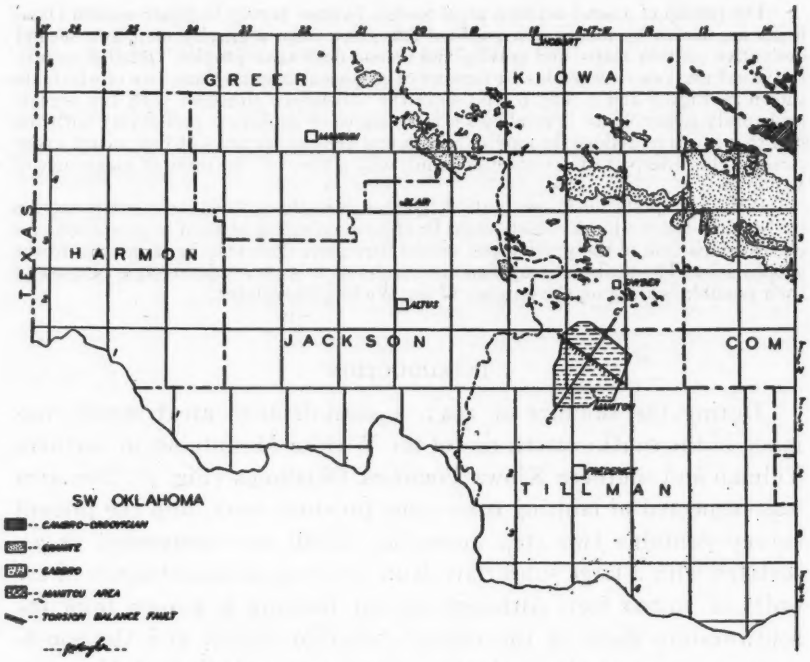


FIG. 1. Location of area surveyed.

in the direction of the curvatures across this zone, are conspicuous features of Fig. 2.

GRAVITY MAP

Gravity was calculated in the conventional manner, and contoured at an interval of one milligal (Fig. 3). The station observed near the SW corner of the NW quarter of sec. 32, T 2N, R 17 W was chosen as the base, and was assigned an arbitrary value of +100.0 milligals, because it was obvious from neighboring stations that gravity would decrease rapidly in a southwesterly direction. With reference to this point, gravity decreases more than 70 milligals to the southwestern edge of the area, and increases more than 5 milli-

gals to the E. and NE., where a closure is indicated by very small or reversed gradients.

The most important feature of Fig. 3 is the band of closely spaced isogals in the central portion of the map, or in the zone of large gradients mentioned above.

SECOND DERIVATIVE MAPS

The direction of the isogals is approximately N 55° W–S 55° E, and the same direction was found to prevail in the contour maps of

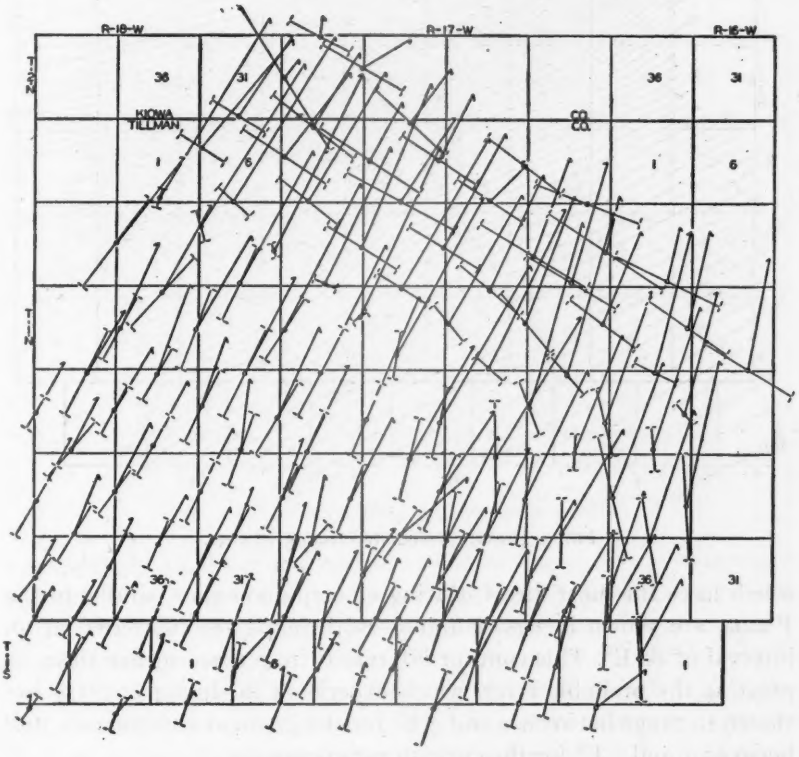


FIG. 2. Gradients and curvatures.

the gradients and curvatures, which were prepared for the purpose of re-orienting the reference axes for the second derivative analysis. This direction was made parallel to the Y'-axis, with the positive branch directed S 55° E. Therefore, the X'-axis had a direction of N 35° E, with the positive branch to the NE.

All second derivatives were recomputed with respect to this sys-

tem of axes, and then contoured on four separate maps.[1] The maps of the two principal gradient and curvature components, $U_{X'Z}$ and $U_{\Delta'}$,

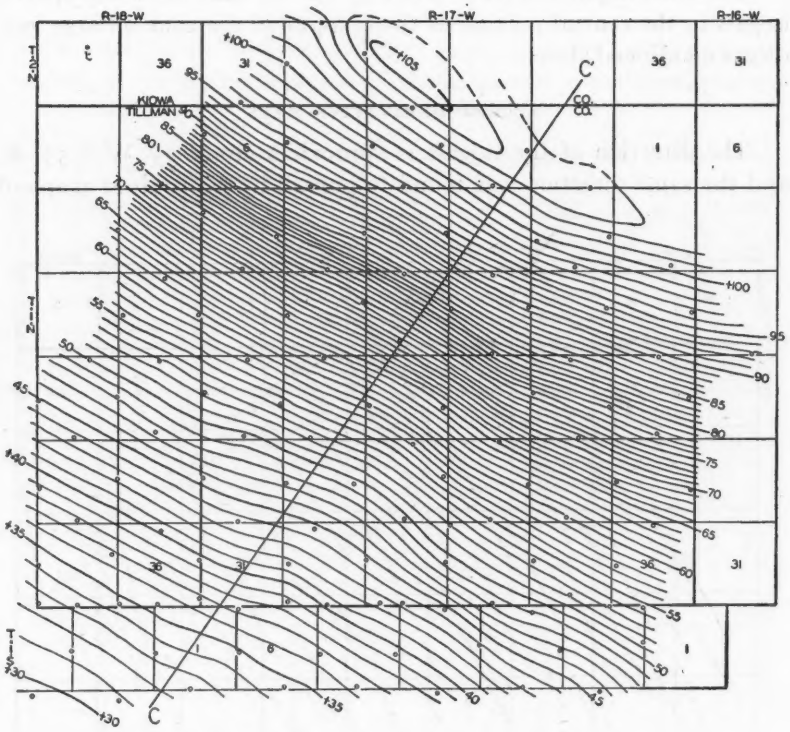


FIG. 3. Gravity, calculated from gradients.

which have the most direct bearing on step anomalies parallel to the Y'axis, are shown in figs. 4 and 5. Both maps are contoured at an interval of 10 E°. This contour interval is from three to five times as great as the probable error, which experience in similar country has shown to range between 2 and 3 E° for the gradient components, and between 3 and 5 E° for the curvature components.

In Fig. 4, we note two pronounced maxima of $U_{X'Z}$ in the central portion of the map. These maxima show very definite elongation parallel to the Y'-axis, which is one of the criteria for step anomalies. The southwestern maximum shows an almost constant value of +120

[1] H. Klaus, *An Introduction to the Second Derivative Contour Method of Interpreting Torsion Balance Data*, GEOPHYSICS, Vol. III, No. 3 (July 1938), pp. 234–246.

E°, from the south central part of Sec. 1, T 1N, R 18W, to the northwestern part of Sec. 21, T 1N, R 17W. From this point to the SE, this maximum declines rapidly in relief and absolute value, and reaches a value of +60 E° in the NE quarter of Sec. 2, T 1S, R 17W. This condition should be carefully noted, as it furnishes an important point

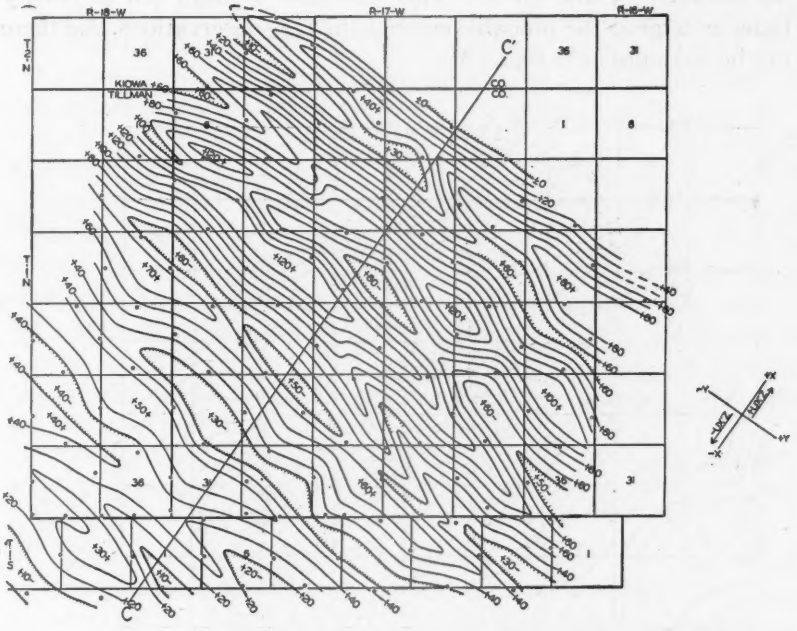


FIG. 4. $U_{X'Z}$ contour map (gradient components).

in support of the final interpretation of this step anomaly adopted in this paper. Note also that this maximum is fairly smooth and sharp. In contrast hereto, the northeastern maximum of $U_{X'Z}$, along its course from the southern part of sec. 6 to sec. 25, T 1N, R 17W, is decidedly "bumpy." It shows at least four bumps or small local highs, and the relief does not decrease as rapidly southeastward as in the case of the southwestern maximum. It is important to note these points carefully, as they have a very definite bearing on the degree of probability of the interpretation finally adopted. These points cannot be brought out in the profiles, unless a whole series of profiles is constructed, and they demonstrate one of the principal uses of second derivative contour maps, which is: to observe the behavior of an anomaly along its strike. Note also that the southwestern maximum is

parallel to the Y'-axis along its entire course, while the northeastern maximum takes a more westerly course in the western half of the map so that the two maxima approach each other quite closely in sec. 1, T 1 N, R 18 W. However, even there, as throughout the map, the two maxima are separated by a pronounced minimum which ranges in relief between 15 and 50 E°. This minimum is from ten to twenty times as large as the probable error of the U_{XZ} observations, and there can be no doubt as to its reality.

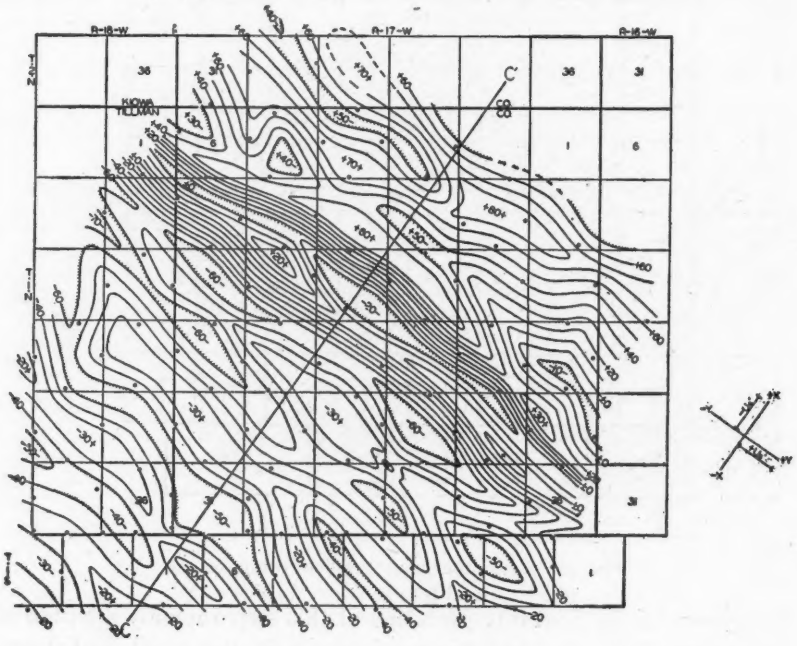


FIG. 5. $U_{\Delta'}$ contour map (curvature components)

The other patterns shown on this map, including several anticlinal reversals, have no bearing on the step anomalies and are beyond the scope of this paper.

The outstanding features of the $U_{\Delta'}$ contour map, Fig. 5, are two bands of closely spaced contours in the central portion of the map, or in the same zone where we noted the abrupt change of direction of the curvatures in Fig. 2. These bands of closely spaced contours are diagnostic of step anomalies, and they furnish the principal evidence against a purely anticlinal interpretation of the main anomaly of this

survey. It is easily noted at a glance that both bands of contours traverse the area of the survey in its entirety; but there are some important distinctions between the two. The northeastern band of contours is somewhat more closely spaced than the southwestern one. It reaches a maximum relief of over 80 E° (from the high to the low closure to the South) in secs. 9, 10, 15, 16, and 22, T 1 N, R 17 W. The relief diminishes slowly to the NW of this area, and more rapidly to the SE of it.

The southwestern band of contours has two areas of maximum relief, separated by an area of rather low relief. The northwestern maximum of relief occurs across secs. 7, 8, 17, and 18, T 1 N, R 17 W, and the relief here exceeds 80 E°. To the NW of this area, the relief diminishes very slowly, and increases again at the NW edge of the map. The southeastern area of maximum relief occurs across secs. 22, 23, 26, and 27, T 1 N, R 17 W. This maximum exceeds 70 E°. It diminishes slowly northwestward, and very rapidly southeastward; so rapidly, indeed, that it reaches the vanishing point in the SE quarter of sec. 36, T 1 N, R 17 W. This should be noted in conjunction with the behavior of the southwestern maximum of the $U_{X'Z}$ component in the southeastern portion of the map, noted above.

The relative positions of the centers of the $U_{X'Z}$ maxima and the centers of the closely spaced bands of $U_{\Delta'}$ contours are typical of step anomalies.

Other $U_{\Delta'}$ contour patterns of anticlinal, synclinal, and buried hill character are present in Fig. 5, but will not be discussed at this time.

The contour maps of the $U_{Y'Z}$ and $2U_{X'Y'}$ components are not shown here, as they have very little bearing on the step anomalies. They do have some bearing, as evidenced by large negative $U_{Y'Z}$ values in the southeastern half of the map, with average or regional values in excess of -20 E°. This indicates a regional gradient component directed N 55° W, or pointing in the direction of the increase of relief of the sharp local density discontinuities indicated by the major second derivative components. It will be noted that this agrees with the behavior of the second derivative patterns of the major components in the southeastern portion of the map.

Likewise, the $2U_{X'Y'}$ map shows large local and regional plunge patterns, plunging southeastward, in the southeastern part of the map, confirming the data given above.

While these maps are not shown here, the writer will be glad to furnish copies to anyone seriously interested in the study of this material.

GRAVITY AND SECOND DERIVATIVE PROFILES

Figures 3, 4, and 5 show the location of profile C–C', along which vertical sections of the gravity, $U_{X'Z}$ and $U_{\Delta'}$ contour maps were constructed. Vertical sections were constructed along several other profile lines parallel to the X'-axis, but profile C–C' was considered to be the most representative. This is certainly true for the gravity and the $U_{X'Z}$ component, but might not be true for the $U_{\Delta'}$ component (see Fig. 5), because the line C–C' crosses the southwestern band of closely spaced contours in an area of minimum relief (sec. 21, T 1 N, R 17 W), and the northeastern band in an area of maximum relief (sec. 16, T 1 N, R 17 W). Therefore, this fact should be borne in mind when

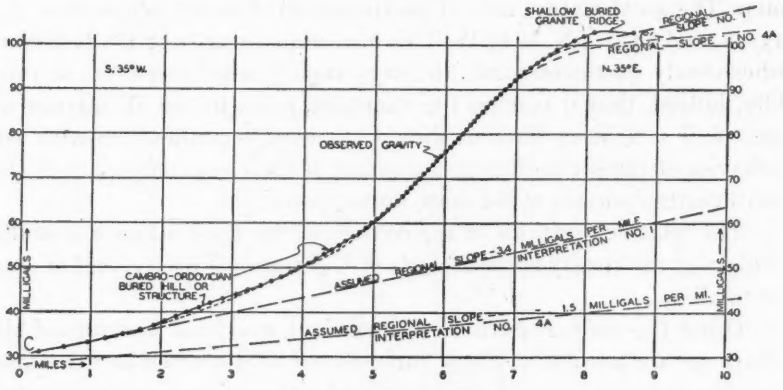


FIG. 6. Gravity profile C–C'.

studying the $U_{\Delta'}$ profile. More nearly average conditions, as far as $U_{\Delta'}$ is concerned, prevail in the area from 1 to 4 miles NW of C–C', and in the area from $1\frac{1}{2}$ to $3\frac{1}{2}$ miles SE of C–C'.

The gravity profile, Fig. 6, is regarded as a typical step anomaly profile, modified by a large local high of the stepped-up side, near mile 8, and by smaller local highs between miles 2 and 3, and between miles 4 and 5. To demonstrate the nature of the gravity anomaly convincingly, the survey should have been carried some 4 or 5 miles farther to the NE, since significant changes of the curve in that direction might conceivably enlarge to a considerable extent the high centering near mile 8, and reduce to a considerable extent the contributions of the step anomalies to the total gravity curve. However, the detailed examination of the second derivative curves makes such a de-

velopment highly improbable. In view of the fact that gravity was put only to a very limited use in this analysis, and that the structural information was chiefly derived from the second derivatives, it was not considered necessary to delay this paper until the survey could be extended some 4 or 5 miles to the NE.

For the quantitative calculations, this gravity curve was used merely as a means of estimating the possible range of magnitude of the step anomalies which might be contained in the curve, under various assumptions of regional gravity slope.

In the first experiment, the regional gravity slope was assumed to be 3.4 milligals per mile, rising northeastward in the direction of profile *C–C'*. It was also assumed that the portion of the gravity curve between miles 0 and 1 fell into the regional slope, and that the curve returned to the regional slope, on the stepped-up side, a short distance NE of mile 10, after crossing it at mile 8.6, due to a topographic or structural depression in the surface of the granite between miles 9 and 10. Under these assumptions, the combined magnitude of the step anomalies was 43.8 milligals (see for instance Fig. 8, the first interpretation attempt), and testing them quantitatively, it was found that the regional slope was given too large a value, and that a considerable gravity effect was already present at mile 0, or at the SW end of the profile, due to the various geological steps assumed. Therefore, the interpretation was modified step by step, until an assumed regional slope of 1.5 milligals per mile, and a local value of +2.0 milligals of the observed curve at mile 0, came very close to fitting the data. This regional slope is shown near the bottom of Fig. 6, labelled "Interpretation No. 4-*A*." This assumption yields an aggregate step anomaly of 60 milligals, or 80% of the total observed anomaly. Under this assumption, the local high near mile 8 is considerably larger than under the first interpretation, and there is a larger topographic or structural depression in the igneous rocks between miles 9.3 and 13. Since the igneous rocks come to the surface at mile 13, this depression, if it exists, could probably be demonstrated by the extension of the survey to the NE, as suggested above. At any rate, the figure of 60 milligals as the aggregate effect of the local step anomalies contained within the area of this survey is important as the upper limit of the range of possibilities within which the geological interpretations may be varied.

The general type of interpretation at the upper limit of the range is shown in Fig. 9. Of the 60 milligals, 53 have been assigned to the large subsurface fault, resulting in a throw of 10,600 feet at a density

contrast of 0.4, assuming that 80 feet of material of unit density contrast will produce an anomaly of 1 milligal. Using the more accurate value of 78 feet, (1, 1940, p. 115) the throw is reduced to 10,335 feet, or the density contrast to 0.39. The remaining 7 milligals have been assigned to a buried granite bluff with a vertical height of 1,400 feet (1,365′); this buried bluff if interpreted as the remnant of the original fault bluff, at the time of burial under Permo-Pennsylvanian rocks, having receded by erosion more than a mile northeastward from its original location at the fault plane, and having been cut down by erosion to the amount shown in Fig. 9.

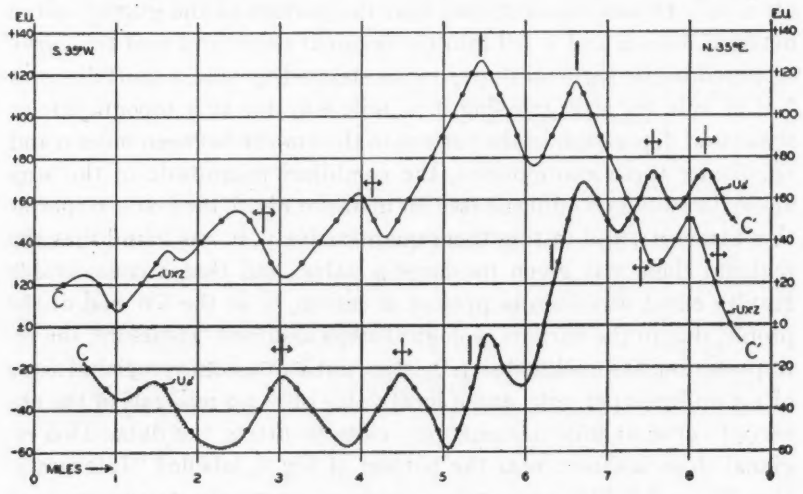


FIG. 7. $U_{X'Z}$ and $U_{\Delta'}$ profiles C–C' (gradient and curvature conponents).

From the gravity profile we cannot be certain of the fault interpretation, at least not until the survey has been extended to the NE. Until that time, it would be possible to consider the profile shown in Fig. 6 as the SW flank of a very large gravity high, culminating near mile 8, and then returning to the northeastward projection of the lower regional slope. No such interpretation appears possible of the second derivative profiles C–C', shown in Fig. 7. These profiles are clearly dominated by the step anomaly discussed above in connection with the second derivative contour maps. The profiles were constructed from these maps, and their locations are identical with that of the gravity profile. More detailed profiles should be obtained, of course,

by direct observations with very small station intervals near the critical points, for a more exact evaluation of the survey.

The smooth curve represents the gradient component, $U_{X'Z}$. This curve must be imagined as composed of the following individual elements:

(1) A regional curve, corresponding to the regional gravity slope;
(2) Two large step anomaly curves or maxima;
(3) Several smaller anomaly curves of anticlinal and synclinal character.

Of chief interest are the two peaks associated with the two step anomaly curves, or maxima. The distance between the peaks is 1.17 miles, and the curves are so steep that the locations of these peaks could be presumed to have been displaced but very little from the locations of the corresponding peaks of the single curves. These peaks were used, therefore, as the locations of the tops of the two single geological steps producing the curves, in constructing the geological profiles. This was borne out by the quantitative calculations (see the gradient values at stations Nos. 11 and $13X_0$ in table No. I).

The hachured curve represents the U_Δ' component of the curvatures. Again, this curve must be imagined as composed of several individual contributions, analogous to those listed above for $U_{X'Z}$. The two largest individual contributions are two step anomaly curves changing from negative values, on the SW, to positive values, on the NE. It is obvious that the combination of these two curves dominates the U_Δ' profile of Fig. 7. The rapid change in values from -60, at mile 5.1, to $+70$, at mile 6.7, takes place in two separate steps of very steep slope. However (unlike the gradient peaks), the mid-points of these slopes cannot be used directly in the interpretation, due to the mutual interference of the two component single curves.

The problem, then, is to design a geological profile in such a manner as to produce two step anomaly $U_{\Delta'}$ curves which will add up to the combination shown in Fig. 7, or to be implied from Fig. 5, besides satisfying the requirements of the gradient and gravity curves.

HYPOTHETICAL GEOLOGICAL PROFILE C–C′

The first attempt to construct a geological profile to meet these specifications is shown in Fig. 8. We have a fault of 6,000 feet of throw, down to the SW, with the fault plane dipping 51°. The upper part of the fault is an ancient granite escarpment, buried in post-uplift Pennsylvanian and Permian formations. Next, following the fault

plane down-dip, we have a zone without density contrast, with pre-uplift sediments faulted against granite, and finally the upper portion of the acidic complex faulted against the lower. Following the fault plane down-dip again, we have the rest of the acidic complex (granites, granophyres, porphyries, etc.) faulted against the basic igneous complex (gabbros, anorthosites, etc.). These assumptions lead to a double step anomaly along the same fault of sufficient magnitude to

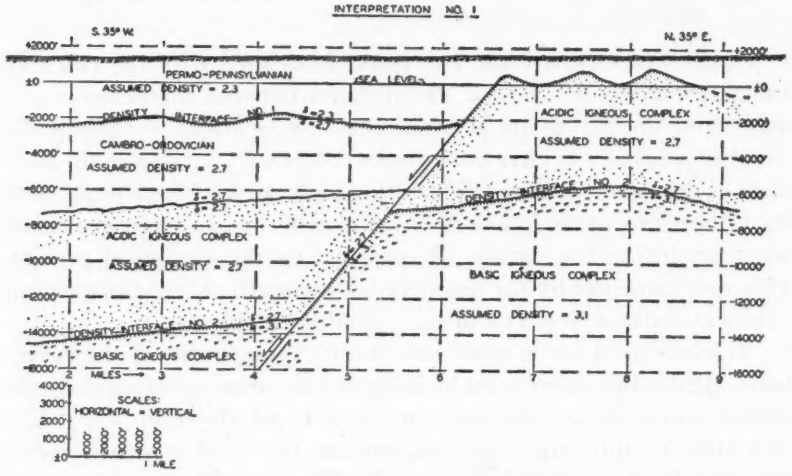


FIG. 8. Interpretation No. 1.

satisfy the indicated gravity anomaly with the assumed regional slope of 3.4 milligals per mile, which was 43.8 milligals. Thirty milligals of this are assigned to the lower density interface, corresponding to a fault of 6,000 feet of throw, at a density contrast of 0.4 (0.39, if Nettleton's more precise value is used; 1, 1940, p. 115), and 13.8 milligals are assigned to the upper portion of the fault, or buried granite escarpment, which then must have a vertical height of 2,760 feet at a density contrast of 0.4 (0.39).

The geological objections to this first interpretation are numerous. The angle of the fault is too low, and the buried granite escarpment too high, to be probable, to mention only a few points. The geophysical objections are even stronger, and irrefutable: this crosssection does not produce the second derivative curves shown in Fig. 7. It produces only one peak of the gradient curve, and only one reversal of the curvatures. Besides, the gradient due to the fault already has an appre-

ciable value of 5.6 E° at the SW end of the profile (at station No. 1 or mile 0.5). This means that the regional gravity slope must be reduced, and that a local anomalous gravity value due to the fault must be assumed, above the regional slope, at the SW end of the profile. This is shown in Fig. 6 by the regional slope labelled "Interpretation No. 4A."

Changing the geological cross section step by step, the interpretation finally adopted as typical of the area is shown in Fig. 9. This profile shows two separate geological steps, the principal one of which

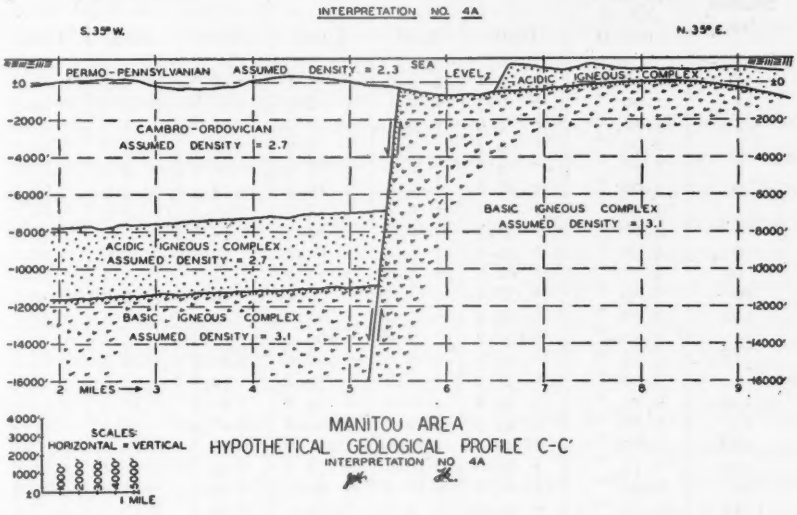


FIG. 9. Interpretation No. 4A.

is a high angle normal fault, dipping 84° to the SW with a measurable (or remaining) throw of 10,600 feet. The trace of this fault is buried under Permo-Pennsylvanian sediments only 1,500 feet below the present surface of the ground. The other geological step is an escarpment in the more resistant granite, which was originally located in the upper projection of the fault, but which has receded northeastward, by erosion, for more than a mile from its original location. Note also that the acidic complex is assumed to be of much lesser thickness than in the first profile (in accordance with prevailing geological opinion), and that most of it has been removed by erosion from the up-thrown side of the fault.

DEGREE OF PROBABILITY OF INTERPRETATION NO. 4A

In order to judge the degree of probability of the interpretation shown in Fig. 9, two separate tests were applied. The first one was a set of quantitative calculations of the $U_{X'Z}$ and $U_{\Delta'}$ effects, and the second one was a detailed consideration of the geological probability of this cross section. For the quantitative calculations, Heiland's formulas Nos. 7–93c were used (2, 1940, p. 260). Only the step anomalies

TABLE I. CALCULATED EFFECTS OF THE STEP ANOMALIES OF FIG. 9

Station No.	Distance, NE of mile 0	Gradients, E°			Curvatures, E°		
		Fault	Bluff	Total	Fault	Bluff	Total
1	0.50 mi.	+ 5.1	± 0.0	+ 5.1	−20.2	− 2.3	−22.5
2	1.00 "	+ 6.3	∓ 0.1	+ 6.4	−21.6	− 2.7	−24.3
3	1.50 "	+ 7.9	+ 0.1	+ 8.0	−24.2	− 2.9	−27.1
4	2.00 "	+ 9.7	+ 0.2	+ 9.9	−27.0	− 3.0	−30.0
5	2.50 "	+ 13.6	+ 0.3	+ 13.9	−30.0	− 3.4	−33.4
6	3.00 "	+ 18.7	+ 0.4	+ 19.1	−34.2	− 3.9	−38.1
7	3.50 "	+ 23.2	+ 0.5	+ 23.7	−38.1	− 4.6	−42.7
8	4.00 "	+ 33.7	+ 0.6	+ 34.3	−42.5	− 6.6	−49.1
9	4.50 "	+ 49.5	+ 0.7	+ 50.2	−45.3	− 6.8	−52.1
9a	4.75 "	+ 62.1	+ 0.9	+ 63.0	−44.5	− 7.7	−52.2
10	5.00 "	+ 78.1	+ 1.0	+ 79.1	−40.0	− 9.0	−49.0
10a	5.25 "	+ 90.4	+ 1.6	+ 92.0	−25.5	−10.4	−35.9
11	5.50 "	+106.4	+ 2.8	+109.2	+ 5.9	−13.1	− 7.2
11a	5.75 "	+ 91.2	+ 4.8	+ 96.0	+26.5	−16.3	+10.2
12	6.00 "	+ 71.0	+ 8.8	+ 79.8	+40.8	−22.0	+18.8
12a	6.25 "	+ 54.8	+20.6	+ 75.4	+48.2	−30.3	+17.9
13	6.50 "	+ 43.7	+60.5	+104.2	+46.9	−25.4	+21.5
$13X_0$	6.625 "	+ 39.2	+75.8	+115.0	+45.8	+21.0	+66.8
13a	6.75 "	+ 35.6	+36.6	+ 72.2	+44.8	+40.1	+84.9
14	7.00 "	+ 29.0	+11.7	+ 40.7	+42.4	+27.0	+69.4
14a	7.25 "	+ 22.6	+ 5.1	+ 27.7	+39.5	+18.8	+58.3
15	7.50 "	+ 20.2	+ 3.0	+ 23.2	+36.8	+14.5	+51.3
16	8.00 "	+ 15.2	+ 1.4	+ 16.4	+32.7	+ 9.7	+42.4
17	8.50 "	+ 11.5	+ 0.8	+ 12.3	+29.0	+ 7.3	+36.3
18	9.00 "	+ 8.8	+ 0.3	+ 9.1	+26.1	+ 5.9	+32.0
19	9.50 "	+ 7.3	+ 0.2	+ 7.5	+23.6	+ 4.8	+28.4

were calculated, and the other local and regional anomalies were entirely disregarded. For this reason, no graphical comparison of the calculated and observed results is shown, and the omission of these anomalies should be taken into consideration when studying table No. I.

A study of this table shows that the step anomalies of fig. 9 will reproduce the essential central portions of the two second derivative curves of Fig. 7 with a high degree of approximation. Add +9.3 E° to the gradient values, to correspond to the regional gravity slope of 1.5 milligals per mile, and add the corresponding effects of the other

local and regional anomalies shown in Fig. 9, and the fit is so good that only minor modifications of the geological profile are necessary for a perfect fit. The situation is very similar with respect to the $U_{\Delta'}$ values, but it should be remembered that profile *C–C′* is not the most representative for this component. Conditions more nearly like the calculated values exist both to the NW and the SE of the location of profile *C–C′*. It is concluded, therefore, that Fig. 9 shows the type and order of magnitude of the geological steps which will reproduce the observed second derivative profiles of fig. 7.

It should be mentioned here that a modified version of Fig. 9, embodying a reverse fault of the same throw, dipping 96°, also was calculated. The results show a pronounced asymmetry of the first gradient peak, which is improbable from the present data, but might be substantiated from more detailed work later on.

Considering the geological probability of Fig. 9, normal faulting is the general rule in the Wichita-Arbuckle Geosyncline, although thrust faulting near the town of Sulphur, in the Arbuckle Mountains, has recently been reported by Lehman (13, 1945). The faults in the Amarillo Uplift and the Muenster Arch, which are the northwestern and southeastern extensions, respectively, of the Wichita System, may be studied on Sellards' "Structural Map of Texas" (14, 1936). As to the size of the faults, Tomlinson (9, 1928; 10, 1929) shows a throw of about 12,000 feet for the fault cutting the SW flank of the Criner Hills. Taff's maps and cross sections of the Arbuckle and Wichita Mountains (3, 1928) show numerous normal faults and one reverse fault, but no precise figures as to throw are given, or can be derived from the cross sections. However, he cites one locality south of Wapanucka, where two nearly parallel faults approach each other, "and their combined throw brings Devonian shales almost in contact with the granite, concealing 8,000 feet of Cambrian, Ordovician, and Silurian strata" (3, 1928; p. 39). Since Taff wrote his report, much work has been done on these formations, and many sections have been measured (5, 1928; 6, 1931; 17, 1930). The thickness of the strata cited above would now be regarded more nearly as 11,000 feet instead of 8,000 feet. This fault, therefore, is of approximately the same magnitude as the one shown in Fig. 9. Melton (17, 1930, p. 19) emphasizes the block-mountain nature of the Wichita-Arbuckle diastrophism. Van der Gracht (4, 1931, p. 1007), after reviewing the entire region, fully endorses Melton's ideas, and states: ". . . faulting seems to have been the chief mode of deformation in the Wichita Mountains; though folding is an increasingly important factor toward the south-

east, it seems to gradually disappear westward. The abrupt slopes on the north side of the main Arbuckle and Wichita Mountain arches constitute fault-line scarps. They are to a very considerable extent block mountains, notably the western units." Faulting, then, is considered to play a more important role in the diastrophism of the Wichita Mountains than in that of the Arbuckles. At the same time, faulting is much more difficult to demonstrate in the Wichitas, due to the fact that they have been much more severely denuded than the Arbuckles. The pre-uplift sedimentary formations have been entirely removed from the top of the uplift, and, except for considerable areas on the NE flank and small patches on the SW flank, these formations have been overlapped by post-uplift formations and are now concealed beneath a blanket of these younger formations. Therefore, the structure of the Wichitas cannot be studied at the surface, except for restricted areas, and we must depend on geophysics to establish the basic structural features of these mountains.

According to Becker, the magnitude of the uplift of the Wichitas, measured from the bottom of the Palo Duro Basin, is 17,300 feet (16, 1930, p. 44). If the interpretation of Fig. 9 is adopted, it means that at least 61% of this uplift is accomplished by faulting. In view of the degree of faulting cited above for the Criner Hills and the Arbuckles, and in view of the predominating geological opinion that faulting increases in importance in a westward direction, the fault of Fig. 9 appears to be both reasonable and probable.

The physiography of the mountains points to certain structural features. Thus, Melton and Van der Gracht (17, 1930; 4, 1931) consider the abrupt north slopes of Mt. Scott, Mt. Sheridan, and Mt. Wall to represent the remnants of a fault scarp. It will be noted that the buried pre-Permian surface of Fig. 9, particularly the granite bluff at mile 6.6, and the low area developed in the gabbro to the south of this bluff, constitute the exact counterpart of the physiography near Mt. Scott, preserved at a more youthful stage of development by burial under post-uplift formations which, of course, stopped erosion in late Pennsylvanian or early Permian times.

As to the densities, and corresponding density contrasts, shown in Fig. 9, the writer concedes without argument that he chose the extreme values of the possible ranges. Therefore, a downward revision of the density contrasts is very probable, This means that either the structure is much more pronounced than shown, in order to produce the measured geophysical anomalies with smaller density contrasts, or

that a smaller portion of the total gravity anomaly need be assigned to the geological steps in order to correspond to the structure shown. No exact density information is available from the literature. Hoffman (8, 1940) gives the exact mineral composition of 9 basic and 3 acidic igneous samples, but without porosity data. The densities calculated from these samples, assuming a porosity of 1%, are shown in table II.

TABLE II. DENSITIES CALCULATED FROM HOFFMAN'S SAMPLES OF IGNEOUS ROCKS

(a) Basic rocks	
(1) Anorthosite, NE Area, T 4 N, R 13 W	2.72
(2) Gabbro, Central Area, T 4 N, R 13 W	2.89
(3) Gabbro, SW Area, T 4 N, R 14 W	3.03
(4) Grano-Gabbro, Hazel Quarry T 3 N, R 13 W	3.02
(5) Gabbro, Central Peak, T 3 N, R 14 W	3.01
(6) Gabbro, Boggy Flat, T 4 N, R 15 W	2.83
(7) Anorthosite, Boggy Hollow, T 4 N, R 15 W	2.69
(8) Gabbro, Wolf Creek	2.87
(9) Diabase, locality uncertain	2.98
(b) Acidic rocks	
(10) Granophyre, Saddle Mt.	2.65
(11) Granophyre, Lugert	2.58
(12) Granophyre, Quanah	2.61

It appears entirely inadequate, of course, to estimate the densities of thousands of cubic miles of rock from 12 small samples, but the indications are that the bulk of the basic rock has densities ranging from 2.90 to 3.00, since the anorthosites appear to represent a very local and restricted phase of the rock. Likewise, the bulk of the acidic rock probably ranges from 2.60 to 2.65. For a large part of the Cambro-Ordovician section, detailed mineral compositions are given by Decker and Merritt (5, 1928; 6, 1931), but again without porosity data. At a porosity of 4%, the bulk of the rocks described would have a density of less than 2.65. At a porosity of 6%, the densities would range between 2.60 and 2.62. For the thick dolomitic sections near the base of the Arbuckle, even higher porosity figures appear likely. At a porosity of 10%, the densities in this section would range from 2.61 to 2.71. The general conclusion is that the density contrasts probably do not exceed 0.35, and that they could be lower. At this value, 225 feet of relief would correspond to 1 milligal, and it would require only 48.6 milligals of gravity anomaly for the major fault instead of 53, or the throw should be increased to 11,800 feet, if the gravity anomaly is held constant.

CONCLUSION

The structure shown in Fig. 9 has a high geophysical probability rating, in the light of the detailed evidence recited in this paper. Due

to uncertainties as to densities, revisions are indicated which would increase the relative size of the large local high centering near mile 8, but would leave the throw of the major fault virtually unchanged, by assigning more of the total gravity anomaly to the local high, and less to the fault. The structure, and the buried pre-Permian topography, have a very high geological probability rating. It is concluded, therefore, that Fig. 9 shows a subsurface situation which is very probable as to type and order of magnitude of the individual features composing it. This interpretation implies that a thick section of pre-uplift formations exists on the downthrown side of the fault. This section might be of great interest in prospecting for oil. The conclusion is also inescapable that from gravity data alone, such as would be obtained with the gravitymeter, a solution as to the type of this anomaly, especially the nature of the buried topography, would have been virtually impossible. It is obvious that the second derivatives furnish the detailed evidence for the buried topography. It is also concluded that surveys of this type offer to the geologist the principal opportunity of examining the basic structure of the Wichitas, since examination of the outcrops is denied him by the overlap of post-uplift formations over the pre-uplift formations in about 75% of the critical area.

Before any refinement of the present interpretation can be attempted, the survey should be extended about 5 miles to the NE, and about 3 miles to the SW, and closely spaced torsion balance stations should be added near the critical points of the step anomaly curves. Furthermore, the densities of the rocks involved should be estimated within closer limits, preferably by employing Nettleton's method (1, 1940, p. 57) of observing profiles over granite hills or depressions in a granite topography, with the gravitymeter, over gabbro hills in a gabbro topography, etc. It is also suggested that the inclusion of porosity data in descriptions of rock samples, for instance such excellent ones as Decker's and Merritt's, would be of great help not only to the geophysicist, but also to the geologist.

ACKNOWLEDGEMENTS

The writer is indebted to many fellow geologists and geophysicists for their ideas and suggestions, all of which it would be impossible to acknowledge. He is especially indebted to Mr. J. C. Hughes, of Klaus Exploration Co., for preparing the illustrations.

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GRAVIMETER OPERATIONS IN THE FOOTHILLS BELT OF ALBERTA, CANADA*

W. K. HASTINGS†

ABSTRACT

As part of a gravimeter survey in western Alberta, Canada, the work was extended into quite rugged areas of the Rocky Mountain Foothills belt. This paper outlines the general methods of operation, carried out on horseback from a movable camp, which were employed where conventional methods, using trucks, were impossible. Gravity observations were made with a new, small type Gulf gravimeter which, complete with batteries and other accessories, weighs about forty-eight pounds. The reduced gravity results were quite smooth and regular in spite of rugged topography and terrain corrections running up to 7 milligals.

The gravimeter survey described, in part, in this report covers the foothills belt and part of the adjacent plains of Southern Alberta. The survey extends northward from the American border for a distance of some two hundred miles and has been carried on intermittently from June, 1942 until the present time.

GENERAL METHOD OF OPERATION

All of the area that could be travelled by truck was worked in the conventional manner with the regular Gulf gravimeter[1] and elevations were carried by ordinary leveling with Wye levels. Level closures were kept within 5 cm. multiplied by the square root of the traverse length in miles. Horizontal control was carried by plane table and by survey speedometer where the roads followed the section lines. The major part of the truck work was done as usual, from the nearest town, but in some of the more remote sections, the men camped on the job for a few days at a time, using sleeping bags and doing their own cooking.

In the rougher parts of the foothills, where travel by trucks was impossible, it was necessary to use horses for transportation. A newly developed, small type Gulf gravimeter which could be easily packed was substituted for the standard gravimeter. Fig. 1 indicates the relative sizes of the two instruments. Both horizontal and vertical con-

* Read at the Tulsa and Houston meetings of the Society, 1945.

† Gulf Research and Development Co.

[1] R. D. Wyckoff, *The Gulf Gravimeter*, GEOPHYSICS, Vol. VI, No. 1 (Jan. 1941), pp. 13–33.

trol were carried simultaneously by transit and the men lived in a portable camp. The small gravimeter is also suitable for packing on foot but horses were used exclusively on this project.

The party was divided into two groups and both truck and horseback work carried on at the same time. At about weekly intervals, the key men were moved from one type of work to the other. This gave them an opportunity to be with their families and also made it convenient for supplying the camp and for changing batteries. They could

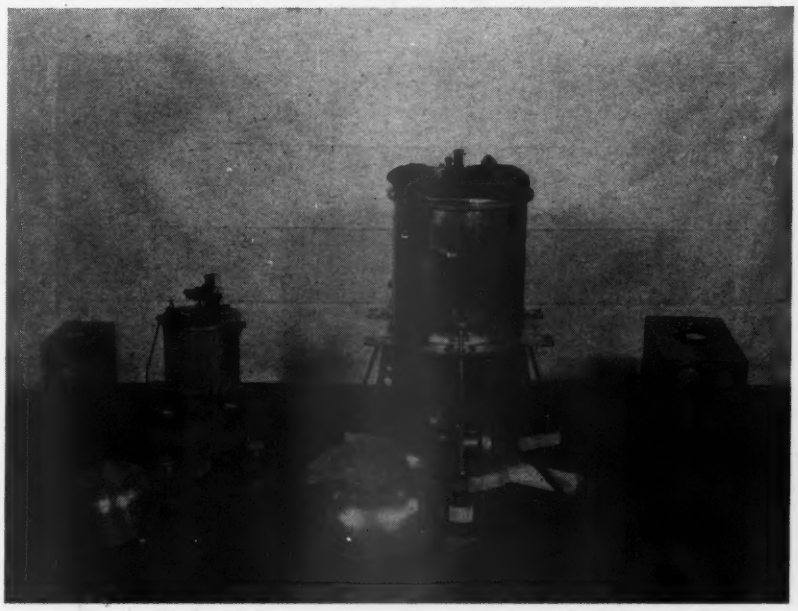

FIG. 1. Standard Gulf gravimeter (right) used for operations by truck, and new small instrument (left), which was used in all horseback operations.

also run their notes in the office and have the use of an electric calculator.

ORGANIZATION OF HORSEBACK WORK

The horseback party consisted of a gravimeter operator, a transit man, and two rodmen. While the horses were becoming accustomed to the work, the operator used a helper but later operated by himself.

A packer furnished the horses, all packing and camping equipment, food, a cook, and an assistant packer. He acted part time as a guide and scouted out trails when necessary, but his main task was to

keep the camp moved up close to the work. The camp was moved at intervals varying from two to five days, depending on the number of trails that could be reached from one location. Trail intersections were used for camp sites whenever possible.

The survey party used four horses, one for the transit man, one for his transit box and tripod, and one for each of his two rodmen (Fig. 2). They took off from the nearest truck station and carried profiles on all of the available trails, looping back into truck stations whenever possible. The longest loop was about eighteen miles. Eleva-

FIG. 2. Gravimeter survey party.

tions were carried by trigonometric leveling and extreme care had to be taken on account of the large vertical angles. Rod levels were used to plumb the rods and the transit man read full stadia and half stadia for a check. The widest elevation closure that was adjusted and used was 2.07 meters, and that particular line contained eleven vertical angles of over 10°, including one of 21°59′, which held the season's record. An angle of that size produces a vertical height of 35 centimeters per meter distance.

For horizontal control, the transit was oriented on magnetic north, with the approximate deviation set off and closure discrepancies ranging up to 300 meters were adjusted. Closure errors by this method were expected because of the rapid change in magnetic declination

but, because of the close check on distances which the vertical control assured, it was not considered worth while to orient on back-sights and thus double the number of setups.

The gravimeter operator rode one horse and led another which carried the gravimeter and battery box (Figs. 3 and 4). When possible, he worked on the same stations during the day as the surveyors, in order to have help within reach if he should need it and to keep the work more closely coordinated. In running a loop, the operator would first observe the same truck station that served as a take-off point for

FIG. 3. Gravimeter operator and helper. Instrument on right side of center horse.

the surveyors. He then proceeded along the profile, observing the field stations in order. As a general rule, he returned to his take-off station in about three or four hours and then re-observed his last field station, which then served as his subbase for the next group of field stations. These short loops were continued until he was able to tie into another truck station and complete his long loop, which he may have worked on for several days. Any discrepancy in the gravitational closure was then adjusted back through the loop. Oftentimes conditions made it impossible to return to a subbase for six or seven hours, and field stations were used where the gravimeter had been away from the subbase for as long as ten hours.

The working season in the foothills with horses runs from about June 1 to October 1. There must be sufficient grass for the horses and the weather cannot be too severe when living in a portable camp.

FIG. 4. Gravimeter pack. Gravimeter on right side, battery box on left side.

Besides the six horses mentioned above which were used in the routine work, it required one each for the packer, his assistant, and the cook, and ten or twelve for packing equipment when the camp was moved. A herd of twenty-five horses (Fig. 5) was carried in order to have ex-

FIG. 5. Part of horse-herd for gravimeter party (Burnt Timber Creek, Alberta, Sept. 29, 1944).

tras for those who went lame. The surveyor's and operator's horses were changed every few days, as they had the heaviest work and went lame most frequently. The muskegs caused more trouble than any other thing and several horses went down in them but none was lost. Wild stallions caused some trouble and two of the mares were lost to them during the 1944 season.

Truck work in the foothills can be best done when the ground is frozen because of the many muskegs and usual summer rains. Many logging roads and wagon trails which are impassable during the summer months can be travelled with comparative ease when the ground is frozen. Snow drifts are a winter problem and for that reason, the fall and spring seasons are probably the most suitable.

The Southern Alberta plains can be worked the year around with not much more difficulty than in Oklahoma or Texas. Severe cold spells do not last long at a time and heavy drifting of snow seems to be rather local, so that the work can be shifted around and not very much time lost. Approximately 70% of the annual precipitation of about 17 inches occurs in May through September and about 35% in June and July (based on Calgary and Edmonton averages).

INSTRUMENT USED

The small Gulf gravimeter (Fig. 1) used in the horseback work is essentially a miniature model of the standard size Gulf gravimeter. The weight is reduced from 94 lbs. to 25 lbs., and the total volume is reduced to one-fourth. The length of the spring and the optical path length are both reduced, resulting in a sensitivity of the corresponding reflection of about one-third that of the standard size gravimeter. However, test measurements have shown that this reduced sensitivity has no noticeable effect on the precision of the gravimeter, but more careful reading is required to hold to the same precision. The small gravimeter uses a 6 volt power supply (for internal illumination and temperature control) and can be operated with a single motorcycle battery. The total weight of both gravimeter and power supply is about 48 lbs.

TERRAIN CORRECTIONS

An attempt was made to hold terrain corrections as low as possible by selecting station sites with a minimum of nearby relief. In most cases, there was little choice, particularly in the brushy country where leaving the pack trails meant excessive brush cutting. In that respect,

FIG. 6. West side of Livingstone Range.

it is fortunate that trails practically always follow the path of least relief. Examples of the more severe topography encountered are shown by Figs. 6 and 7.

FIG. 7. Sample of topography encountered in gravimeter survey in Alberta foothills.

Terrain corrections were calculated in the field through Hammer's[2] Zone D in the earlier part of the work. Because of inaccuracies in the topographic maps, it was later found advisable to carry the field survey for terrain corrections through Zone E, which goes out to 390 meters. In the office, terrain corrections were computed on out through Zone J and, in some instances, through Zone M, which extends to about 13.5 miles from the station site. The field survey was made with

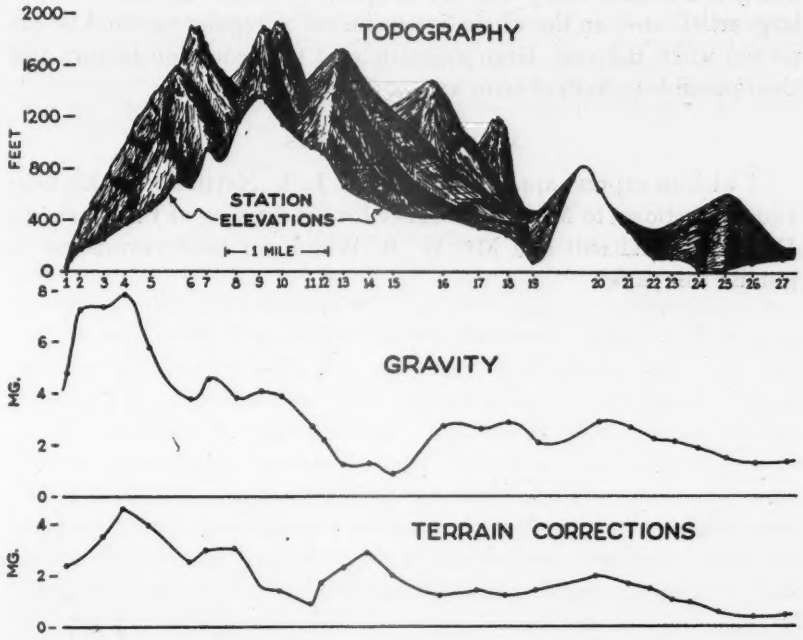

FIG. 8. Sample traverse, showing relative station elevations, topography laterally adjacent to the line of stations (drawn to scale), the reduced (Bouguer) gravity and terrain corrections.

an inclinometer, with distances estimated, and the office terrain corrections were computed from topographic maps, which, fortunately, are available for nearly all the area covered. The average terrain correction for 245 stations in the most rugged area that was worked amounted to 2.38 mgs. Two stations had terrain corrections of over 7.0 mgs.

[2] Sigmund Hammer, *Terrain Corrections for Gravimeter Stations*, GEOPHYSICS, Vol. IV, No. 3 (July 1939), pp. 184–194.

Fig. 8 gives an example of one of the more rugged traverses across the foothills, with the station elevations (relative to an arbitrary datum) and topography laterally from the line of traverse indicated in the upper part. The gravity curve is that for Bouguer anomaly (after free air, Bouguer, and terrain corrections). The bottom curve shows the terrain corrections for each station. While the gravity curve is a little rough in spots, with individual irregularities of several tenths of a milligal, it is quite acceptable for the purpose (as the anomalies are of large relief) and, on the whole, is considered as regular as could be expected when the very large magnitude of the reduction factors and their possible sources of error are considered.

ACKNOWLEDGEMENTS

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"REFRACTION WAVES REFLECTED FROM A FAULT ZONE"*

W. B. ROBINSON†

ABSTRACT

Many records of a reflection project in Webb County, Texas, displayed events showing excessive step-out times. These events are treated as refraction waves following a near-surface marker horizon, and their origin is shown to be associated with faulting which was mapped by the ordinary reflections on the records. Possible confusion that may arise from failing to recognize these anomalous events is discussed as well as the possibility of using the phenomenon to map faults.

A seismograph project in Webb County, Texas, yielded many records with seismic events which displayed step-out times far in excess of those of normal reflections. Many seismic surveys yield an occasional record with an abnormal event, but on this project spreads at about 30 per cent of the shot points showed the steep events. With so much information to work with, it became an interesting problem to attempt to locate the origin of this spurious energy. As will be shown later, the origin probably lies along a fault, but the problem cannot be completely resolved at present because there are too many unknowns. Some refraction shooting probably would evaluate these unknowns and permit a more complete solution. A study of similar events, published by Deacon,[1] was based on observations made in southwest Texas and may be from the same or a similar area as that with which we are concerned here.

Several analyses of the Webb County data have been made using different parameters, and all give about the same location for the main fault. The solution presented herein uses the same vertical velocity distribution for both reflection and refraction calculations, which probably is the most satisfactory approach to the problem.

Fig. 1 shows records from three detector spreads out of the same shot point. The abnormal event may easily be followed continously across the east and west spreads. These spreads are located in a direc-

* Read at the Tulsa, Houston and Dallas meetings of the Society, 1945.

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[1] L. E. Deacon, *An Analysis of Abnormal Reflections*, GEOPHYSICS, Vol. VIII, No. 1, pp. 3–8, January 1943.

tion which is nearly at right angles to the fault. The northeast spread nearly parallels the fault and a strong event is seen on the 200 ft. trace (top trace on bottom record) at the same time (about 2.85 sec.) at which the anomalous event occurred on the close traces of the other records. This event on the northeast spread could easily be mistaken for an ordinary reflection.

Fig. 2 shows records from four detector spreads shot from the same shot point. Abnormal events (indicated by white arrows) are seen at

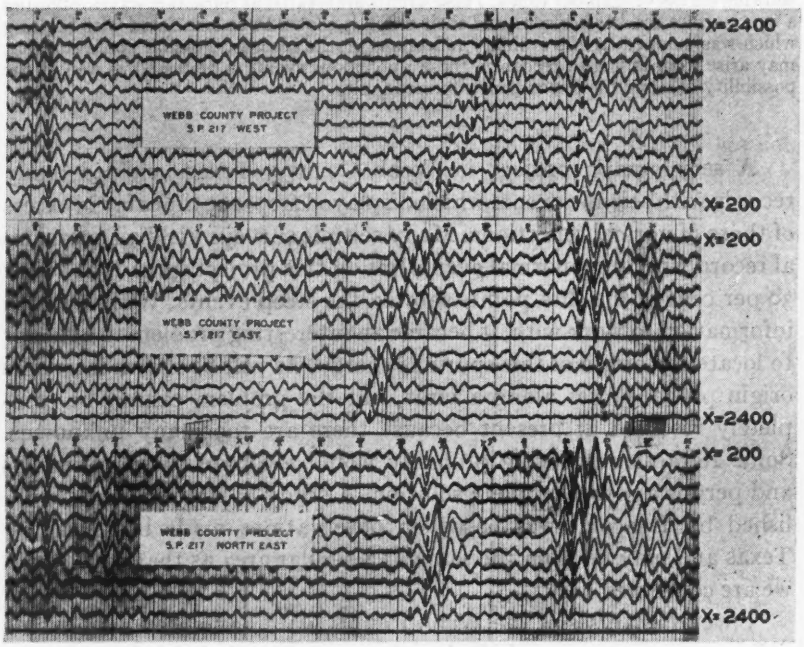

FIG. 1. Seismograph records shot in three directions from the same shot point. The strong event on the top two records has a step-out time far in excess of an ordinary reflection.

about 1.4 seconds on the spreads oriented at an angle from the fault. But again, on the northeast spread which nearly parallels the fault, the event could be mistaken for an ordinary reflection.

Fig 3 shows the paths which the energy is postulated to follow in this discussion. The energy is assumed to travel along a marker horizon, as an ordinary refraction wave, to the fault zone where it is reflected and returns to the detector as a refraction wave. The procedure for locating the fault is as follows:

1. Determine the time consumed in traveling through the material above the marker bed. Subtract that time from the arrival time.
2. The remaining time is assigned to traveling horizontally through the marker bed and can be used to graphically locate the fault zone as explained later.

The time consumed in the beds above the marker depends on the

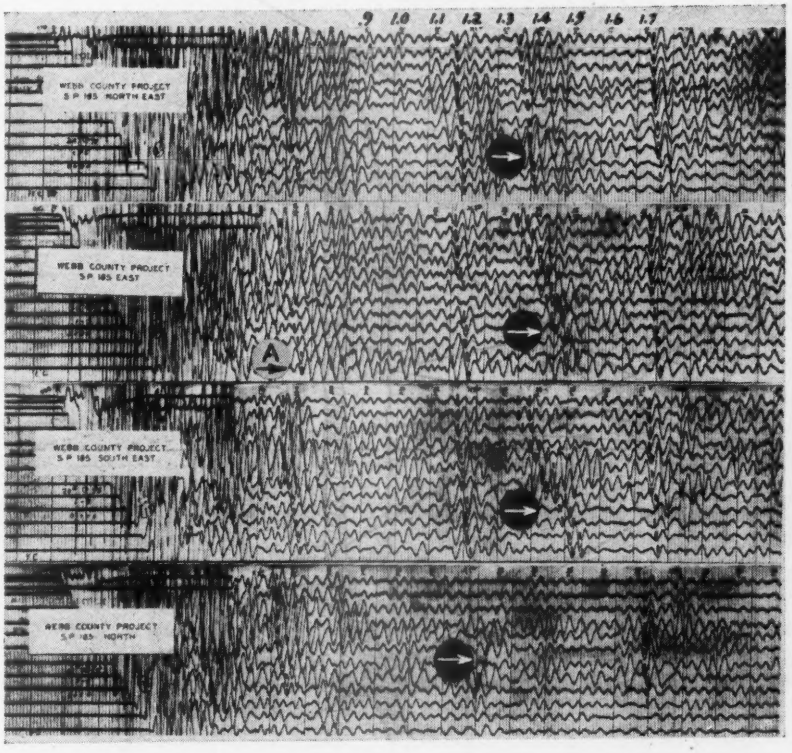
.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
WEBB COUNTY PROJECT S.P. 185 NORTH EAST
WEBB COUNTY PROJECT S.P. 185 EAST
A
WEBB COUNTY PROJECT S.P. 185 SOUTH EAST
WEBB COUNTY PROJECT S.P. 185 NORTH

FIG. 2. Records shot in four directions from the same shot point. Definite events with excessive step-out times are indicated by white arrows. The event could be mistaken for an ordinary reflection on the top record.

assumed depth to the marker and the speeds. The horizontal speed for the marker horizon was determined to be 12,000 feet/second at places where the events were observed on nearby spreads at different azimuths. The vertical speed of the overlying section was assumed to increase linearly with depth.

The assumed vertical speed distribution of $V_i = 7900 + 0.6y$ was supported by T^2 vs. D^2 calculations and was a satisfactory extrapolation from velocity determinations in wells which are some distance away. The same vertical speed distribution was used by Deacon.[2] It is a convenient distribution for a problem like this because the resulting

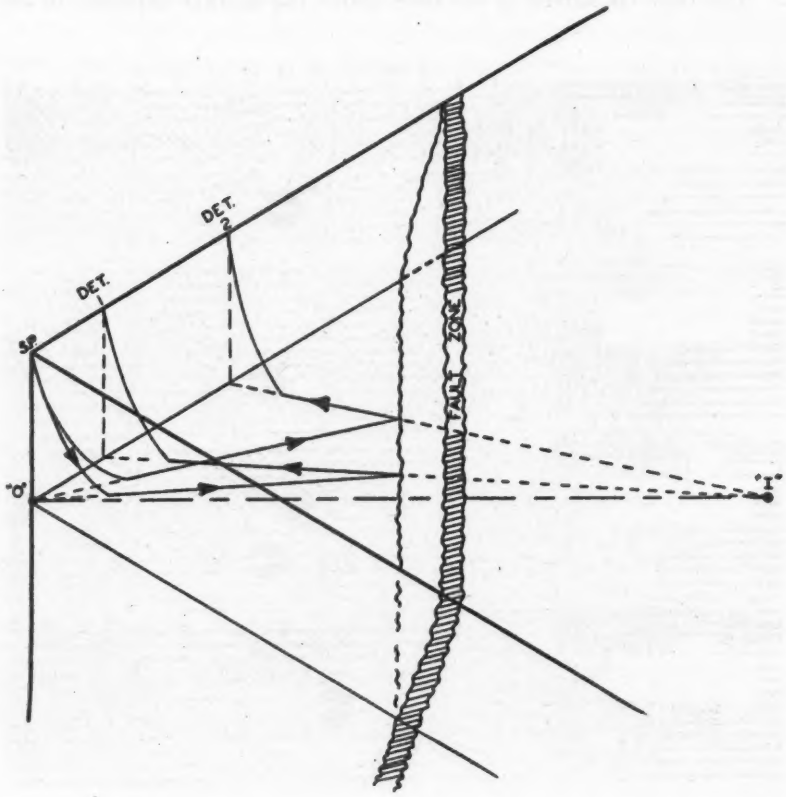

FIG. 3. Diagram showing postulated travel paths followed by the energy which gives rise to the abnormal events. Energy travels as an ordinary refraction wave to the fault zone where it is reflected and returns to detectors as a refraction wave.

wave fronts are circles, and the construction of the necessary charts is simplified.

The evaluation of time consumed in the beds above the marker can be so handled as to correct to points on the marker which are

[2] *Op. cit.*

vertically beneath the shot and detectors. Subtract these corrections from the arrival times, and the data are reduced to conditions that would obtain if the wave started at a point on the marker vertically beneath the shot and returned to a point on the marker vertically beneath the detector. Let the term T_r be used to denote the time remain-

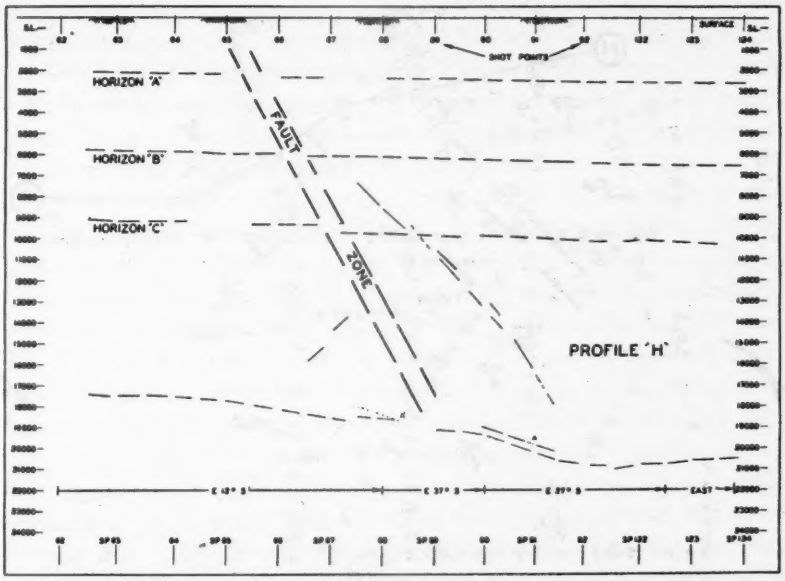

FIG. 4. Profile "H" (of Fig. 5) showing plotted reflections. Horizons "A," "B," and "C" show faulting by character correlations. The very steep segments are the result of plotting abnormal events as ordinary reflections. The abnormal events probably are not simple reflections from a fault face because, here, they call for two faults in close proximity, dipping in opposite directions.

ing after the total arrival time is corrected for travel time in the overlying sediments. The horizontal speed of the marker bed is V_r.

The remaining problem of locating the fault is one of construction which can be handled in at least two ways.

(a) Radii of length $V_rT_r/2$ can be swung from centerpoints (midway between shot and detector) and a tangent to the arcs will locate the reflector.

(b) Radii of length VT_r can be swung from respective detector locations, and their intersection locates an image point, "I." The re-

flector then lies along a normal constructed at the center of a line connecting the point "O" and the image point "I" in Fig. 3.

Figure 4 shows the plotted events allong Profile "H" of Fig. 5.

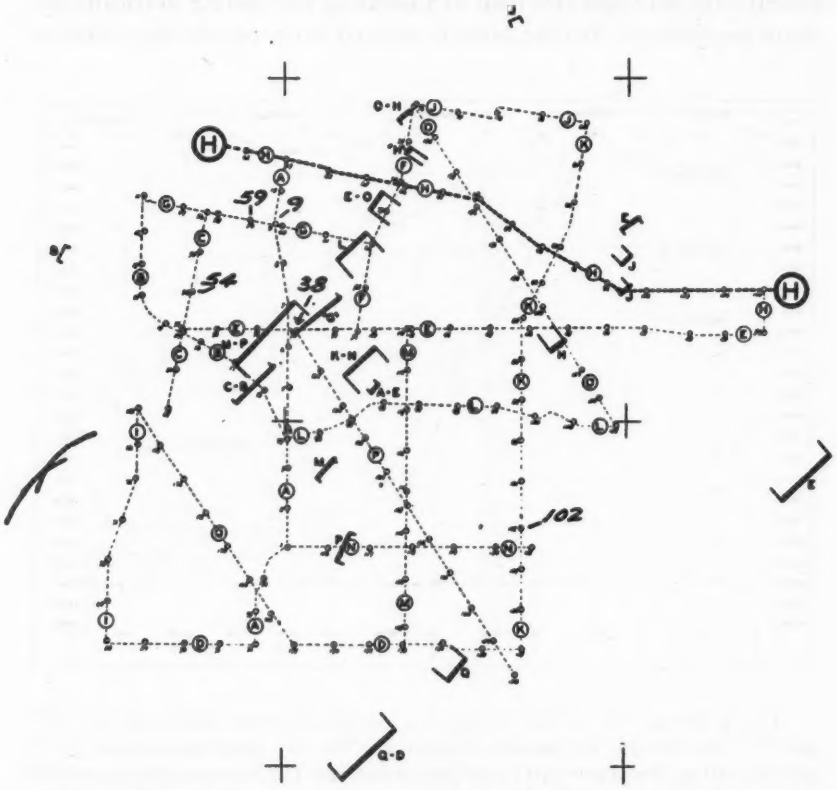

FIG. 5. Heavy bars are fault positions based on assuming the abnormal events to be refraction waves following Horizon "A" and reflected at a fault. Construction arcs swung from center points are shown at left. "Whiskers" point toward the shot point recording the steep event. Fault locations overlap one another indicating that the refraction marker horizon is actually deeper than was assumed.

Horizons "A," "B," and "C" were mapped and are based on persistent reflections which indicate faulting. There is no indication of confused dips within a fault zone; the reflections just end and begin again at a different level. The deep reflection can be offset to the west and fall in line with the fault zone. The steep events are plotted as ordinary reflections. They probably are not reflections from a fault plane, because on this project the steep events from nearby shot points would

call for two faults very close together and dipping in opposite directions. Since the event persists over quite a depth range with the loss of occasional cycles, one could assume that all of the events plotted here come from the same source. The event was followed from 1.5 seconds to 2.9 seconds.

Strong steep events on the project usually were recorded at two time zones; one at about 3.0 sec. and another at about 1.5 sec., as displayed in Figs. 1 znd 2 respectively. The fact that here on Profile "H" we follow the energy across the gap between these two time bands with the same indicated marker speed, suggests that all of the events follow the same marker. The change in apparent dip of the anomalous event on Profile "H" is due to turns in the profile.

The map shown as Fig. 5 was constructed on the assumption that the depth of the refraction marker bed (— 2000 ft.) corresponds to the depth of reflection Horizon "A" in Figs. 2, 4, and 6. The bars (Fig. 5) representing fault positions were located by use of the construction arcs shown at the left of the map in the manner described as (a) above. The "whiskers" point toward the shot point at which the steep event was recorded and are long if the event occurred in the late time zone (about 3 seconds) or are short if the event occurred in the early time zone (1.4 seconds). An inspection of Fig. 5 reveals that the location of a fault based on an event from one direction falls beyond the location determined by an event from the other direction. To avoid this overlapping and bring the two locations into better agreement, we may assume that the waves follow a deeper marker. One limiting factor is that the marker cannot be deeper than the depth corresponding to the earliest time at which the steep event is seen.

A test calculation of marker depth was made by combining arrival times from Shot Points 38 and 102 (see Fig. 5). Half the sum of the two times was considered to be equivalent to the time required for an ordinary refraction event to pass between the two points. The distance between the shot points was scaled, and D/V_r was subtracted from the half time just evaluated, leaving an intercept time. This intercept time represents a depth of 4,200 ft. for the velocities used herein. If time is allowed for the width of the fault zone, the depth will be slightly greater: a 400 ft. fault width gives a new depth of 4,550 ft.

Fig. 6 shows sample records from Shot Points 54, 59, and 9 (located on Fig. 5). Reflections "A," "B," and "C" were mapped and correspond with the horizons shown on Fig. 4. The steep events are very prominent; the event "X" occurs at a total depth of about 4,200 feet

and probably is from the refraction marker horizon since the depth agrees with the test calculation just described.

Fig. 7 shows the new location of faults calculated at the depth of Horizon "X." The locations so determined are in quite good agree-

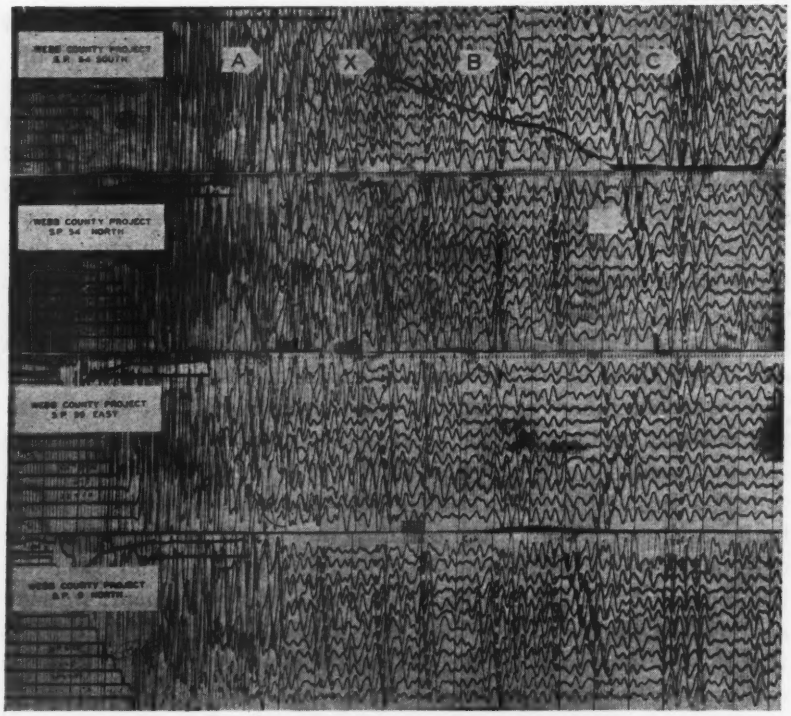

FIG. 6. Sample records showing steep events and good ordinary reflections. Horizon "X" probably is a reflection from the bed which serves as a refraction marker horizon carrying the energy of the steep event.

ment among themselves and suggest fault trends. The concept of "offset distance" should now be considered. For a specific problem a refraction wave will enter the marker at a certain distance out from the shot. The assumption that Horizon "X" is the marker horizon yields theoretical offset distances which correspond with the distance from shot points to the fault locations as determined from the minimum time (1.4 seconds) at which these steep events were recorded.

Fig. 8 shows the Horizon "X" fault locations superposed on the map of Horizon "B", since the Horizon "X" reflection was not mapped.

The fault locations are in good agreement with the fault locations mapped by the reflection method.

Since the refraction fault locations agree very well among themselves with respect to direction and location and also agree with the

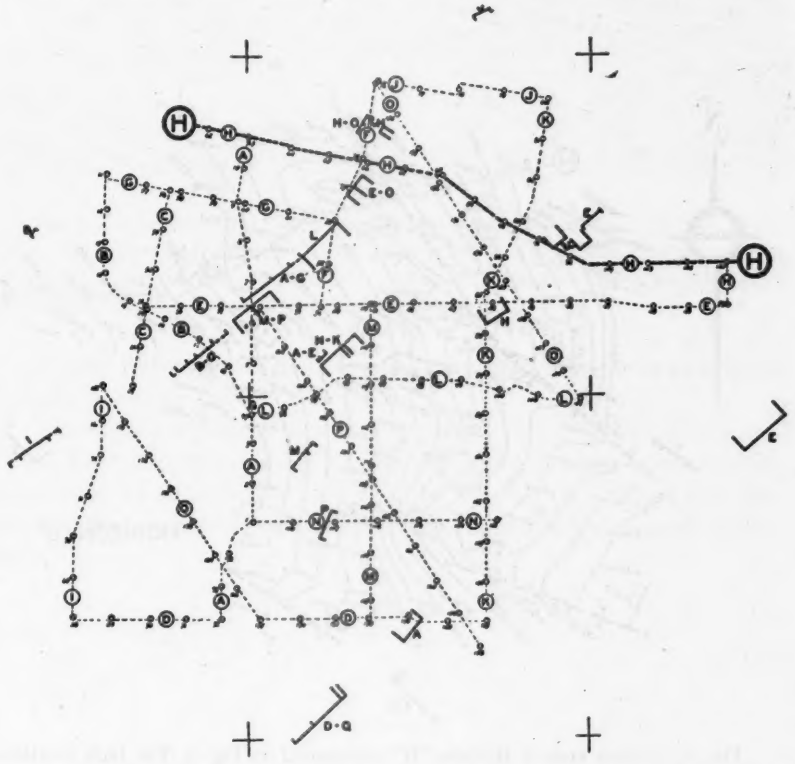

FIG. 7. Fault positions (recalculated from Fig. 5) based on assuming the steep events to be refraction waves following Horizon "X," which is about 2,000 feet deeper than Horizon "A." (See Fig. 6.) Note the improvement in alignment over that in Fig. 5.

fault location shown by ordinary reflection mapping, we may conclude that this is the best solution to the problem at present, i.e., that the abnormal events arise from refraction waves which follow Horizon "X" and are reflected from a fault zone.

Fig. 9 shows confusion that can arise from the use of these steep events if their true identity is not recognized. The steep dip at −6,200 feet at Shot Point 211 is the result of plotting a refraction wave as

though it were an ordinary reflection. If character correlations are carried continously across this shot point, a considerable amount of northeast dip would be shown. The high rate of dip cannot be worked into a reflection interpretation map because the control loops would not close. Furthermore, a jump character correlation between Shot

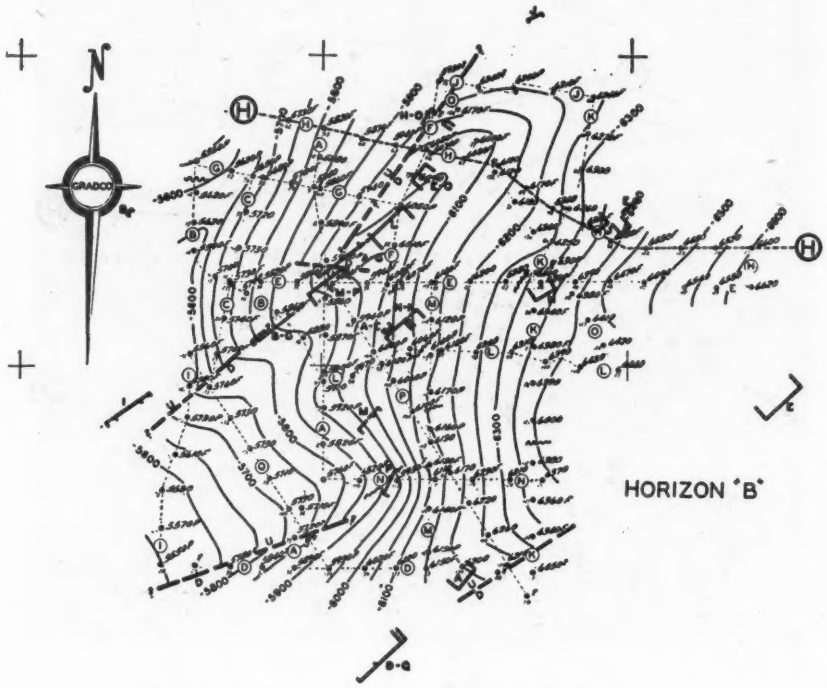

FIG. 8. Contour map of Horizon "B" superposed on Fig. 7. The fault locations determined by the reflection method are in fair agreement with fault locations derived from the steep refracted events.

Points 209 and 212 supports loop closure without faulting. Similar divergence, but of lesser magnitude, would be difficult to detect, and if used, would yield erroneous maps.

Possible application of these steep events would arise if they could be used to trace a fault across a nose where the fault was not certain on correlation maps. Furthermore, the steep events may point to faults which lie beyond the limits of a project and lead the exploration in that direction. The southern point of Texas is one area where, in our

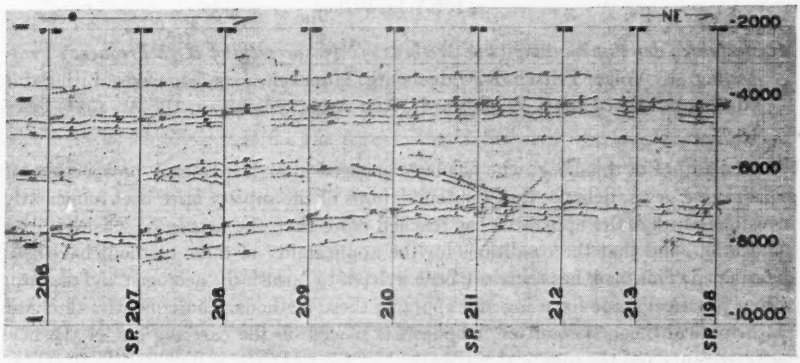

FIG. 9. Depth profile showing confusion between steep events and ordinary reflections. The apparent divergence at shot point 211 is due to an abnormal event being plotted as an ordinary reflection. This dip was not used in the interpretation but similar dips of small magnitude might be difficult to isolate.

experience, these events have been encountered in sufficient numbers to make a study of them.

The author wishes to express his thanks to Drs. P. D. Foote and E. A. Eckhardt of the Gulf Research & Development Company for permission to publish this paper and to Mr. W. D. Johnson and Mr. M. N. Ney for carrying out the calculations and other valuable assistance.

REVIEWS

Messverfahren der Funkmutung (*The Methods of Measurement of High Frequency Prospecting*), by Volker Fritsch. R. Oldenbourg, München, 1943, 220 pages. Lithoprint edition, published by J. W. Edwards, Ann Arbor, Michigan, U.S.A., 1945. Price $5.75.

The author of this book, who has been engaged in high frequency prospecting for some twelve years, believes that the foundations of the subject have been sufficiently investigated, that the apparatus has reached more than the necessary sensitivity for application, and that the conditions for the applicability of these methods have been determined. This book has therefore been written to furnish the geologist and engineer with a practical guide for using and applying these methods. Consequently, the basic mathematical theory is omitted, emphasis is placed on the carrying out of the field measurements and the practical applications of the methods, and numerous diagrams, outlines, tables, and figures are presented to simplify the discussion.

By high frequency prospecting is meant the use of currents or fields of from some hundred thousand up to several million cycles per second. The author's approach to his subject is the reasonable one that there is no question of detecting particular minerals or geologic entities as such but that, as in other geophysical methods, certain physical properties, here electrical ones, are measured and the geologic and mineralogic properties are deduced from these measurements and other relevant information. Specifically, the physical measurements may be of frequency, phase, intensity, and direction of field or current; the electrical properties involved are the conductivity and the dielectric constant; the inverse deduction of the geologic conditions may have many possible solutions and the principal difficulty of the methods is the choice of the solution which best fits already known geologic data.

The first two chapters are introductory, the next two deal with radiation methods, the fifth with resistivity methods, the sixth with sources of error, and the seventh with examples of applications. There is a short bibliography and an index.

The account of the practical applications in Chapter VII will undoubtedly be the portion of the book of greatest interest to those geophysicists who are not themselves specializing in these methods. The author has restricted himself to his own surveys on the ground of greater familiarity with them than with those known to him only from the literature or by correspondence. Many of the surveys are in the nature of tests on known typical geologic situations, but in three cases predictions were made which were later confirmed by geologic investigations or prospecting. The first of these was the prediction of a cave by an underground absorption (field strength) survey; the second, the prediction of another cave by a capacity method; the third, the prediction by a capacity method of a brown iron ore occurrence. The situations studied are either surface or near-surface (of the order of tens of meters) and the usual method a capacity method. One unusual application is the study of the effectiveness of protective measures against lightning by using an alternating current equivalent in certain respects to the lightning direct current.

This is the first book to appear on these "radio" methods and should be of great interest to those concerned with these or with the older electrical methods. The American edition is published by authority of the Alien Property Custodian in the interest of the war effort.

THOMAS A. ELKINS

Magnetic Survey of the Florida Peninsula. F. W. Lee, J. H. Swartz, and S. J. Hemberger. Report of Investigations 3810, U. S. Dept. of the Interior, Bureau of Mines.

The survey was made in 1939 for the purpose of determining the degree of accuracy required for the making of state-wide surveys. Florida was chosen because it was considered to be ideally suited for the experiment. A standard Askania Vertical Magnetometer was used, to which was added a special, built-in calibration coil. The accuracy claimed is ± 3 gammas. All values were adjusted for diurnal variations by means of base-station observations. Normal (Latitude) variation corrections were not applied, however.

The survey itself consists of 15 east-west profiles, about 30 miles apart, extending from the Georgia line southwards to the tip of the peninsula. One profile lies along the highway which extends from Miami through the chain of islands to Key West. The station spacing along the profiles is about one mile.

The data for the profiles are given in tables. Neither profile curves nor a contour map is presented, but a solid magnetic relief map was constructed, and a photograph is shown. This is not a satisfactory method of presenting data, since it is necessary for each interested reader to construct these profiles and contour maps. The photograph of the three-dimensional figure is difficult to interpret.

The conclusions reached by the authors are that the northern portion of the peninsula is geologically a portion of the Appalachian trend, while the southern portion is associated with the Antillean trend. Other conclusions deal with the low cost and the benefit to be derived from the use of the magnetic method for a preliminary geophysical study.

This paper can be secured without cost from the Office of Mineral Reports, U. S. Bureau of Mines, Washington 25, D. C. Due to the limited number of copies printed, only one copy can be sent to the person or institution applying.

JAMES AFFLECK

Geophysical Survey of Arkansas Bauxite Region. J. R. Thoenen, M. C. Malamphy, and J. L. Vallely, Report on Investigations 3791, U. S. Dept. of the Interior, Bureau of Mines.

This is identical with the paper published in GEOPHYSICS, Vol. IX, No. 3 (July, 1944), except that the Bureau of Mines paper has an Appendix giving nineteen pages of logs of holes drilled to investigate geophysical anomalies. Ed.

PATENTS*

ELECTRICAL PROSPECTING

U. S. No. 2,375,775. H. M. Evjen. Iss. 5/15/45. App. 2/25/43. Assign. Nordel Corp.

Electrical Prospecting System. A four electrode variable frequency square wave type of electrical prospecting apparatus using a double commutator and in which the potential is balanced against a potentiometer supplied from the current circuit through a filter which compensates for potential variations due to frequency effects in the current circuit.

U. S. No. 2,375,776. H. M. Evjen. Iss. 5/15/45. App. 4/24/43. Assign. Nordel Corp.

Electrical Prospecting System. A system of electrical prospecting in which commutated d-c is introduced into the ground at several current electrodes whose relative currents are adjusted so that the potential electrodes experience no potential difference during the current gap period.

U. S. No. 2,375,777. H. M. Evjen. Iss. 5/15/45. App. 4/29/43. Assign. Nordel Corp.

Electrical Prospecting System. A four electrode commutated d-c type of electrical prospecting system in which a condenser is connected across the potential electrodes while the current is applied to the current electrodes, and the condenser subsequently allowed to discharge through a potentiometer against which the potential is balanced during the current gap.

U. S. No. 2,375,778. H. M. Evjen. Iss. 5/15/45. App. 2/19/44. Assign. Nordel Corp.

Apparatus for Making Geophysical Explorations. A four electrode commutated d-c type of electrical prospecting apparatus in which the potential electrodes are connected to a galvanometer during the current gap period, this potential being balanced by applying to the current electrodes a second current pulse with reversed direction and observing the ratio of the currents.

U. S. No. 2,376,659. H. Chireix. Iss. 5/22/45. App. 11/18/41 and 3/8/40. Vested in Alien Property Custodian.

Apparatus for Detecting Underground Metallic Objects. A metal finder having a search coil tuned to resonance and connected across a diagonal of a bridge circuit with a-c generator voltage across the other diagonal and indicating bridge unbalance.

U. S. No. 2,378,440. G. N. Scott. Iss. 6/19/45. App. 1/27/41.

Process and Means for Measuring Soil Resistivity and Certain Electrical Characteristics Associated with a Buried Pipe Line. A tractor equipped with a number of movable ground electrodes connected to recording apparatus so that by driving over a pipe line continuous measurements may be made of ground resistivity, potential gradient in the ground, and potential of the pipe with respect to the ground.

GEOCHEMICAL PROSPECTING

U. S. No. 2,374,135. E. E. Roper. Iss. 4/17/45. App. 2/13/41. Assign. Stanolind Oil and Gas Co.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation Patent Department.

Geochemical Surveying. Apparatus for determining hydrocarbons in soil samples by low temperature high vacuum molecular distillation.

U. S. No. 2,374,227. H. E. Metcalf. Iss. 4/24/45. App. 6/17/40. Assign. Consolidated Engineering Corp.

Geochemical Prospecting System. A device for taking soil fluid samples and which inserts an evacuated can into the ground, punctures the can so as to permit entrance of soil fluid and then reseals the can by pressing on a cover.

U. S. No. 2,374,937. L. Horvitz. Iss. 5/1/45. App. 12/21/39. Assign. E. E. Rosaire.

Geochemical Well-Logging. A method of geochemical well logging in which samples are analyzed for at least one ionizable inorganic salt and its concentration correlated with depth.

U. S. No. 2,375,949. R. T. Sanderson. Iss. 5/15/45. App. 2/15/41. Assign. Stanolind Oil and Gas Co.

Geochemical Prospecting. A method of soil gas analysis in which a gas sample is taken from a hole in the ground and a second sample taken and enriched by evaporating into it hydrocarbons caught in a cold trap from the first sample, the two samples being compared by means of platinum combustion wires in a bridge circuit.

U. S. No. 2,376,145. L. Horvitz. Iss. 5/15/45. App. 3/28/41.

Gas Analysis. A method of analyzing soil gas for combustible material which includes preliminary removal by combustion of any combustible material in the oxygen or air which is mixed with the sample for the combustion test.

U. S. No. *2,376,366.* R. C. Lawlor and H. E. Metcalf. Iss. 5/22/45. App. 6/17/40. Assign. Consolidated Engineering Corp.

Geochemical Prospecting System. A method of taking soil fluid samples by means of apparatus which inserts a can into the ground, sucks in fluid and then seals the can with a press-on lid.

U. S. No. 2,377,082. B. Hubbard. Iss. 5/29/45. App. 3/31/42. Assign. Standard Oil Development Co.

Geochemical Prospecting. A method of soil wax prospecting in which samples are extracted with toluene and petroleum waxes identified by orthorhombic crystals obtained from very slow evaporation of the extract.

GRAVIMETRIC PROSPECTING

U. S. No. 2,377,889. L. J. B. LaCoste and A. Romberg. Iss. 6/12/45. App. 8/12/39.

Force Measuring Instrument. A horizontal beam gravimeter supported by a zero length spring pulling at an angle and having a position adjustment at its upper end, auxiliary springs being provided to neutralize the horizontal component of the main spring.

MAGNETIC PROSPECTING

U. S. No. 2,376,883. A. S. Riggs and H. H. Thompson. Iss. 5/29/45. App. 1/30/42. Assign. Sperry Gyroscope Co., Inc.

Dynamic Earth Inductor Compass. An earth inductor compass in which an elastically suspended coil is made to oscillate in rotation by application of a-c in a balanced d-c field, the applied a-c being balanced in the measuring system so that the a-c induced by the earth's field may be indicated.

U. S. No. 2,378,014. P. P. Horni. Iss. 6/12/45. App. 3/24/42.

Method of Determining the Effective Range of Magnetic Detectors. A method of adjusting and calibrating the range of a magnetic detector by constructing its core of overlapping laminations which may be slipped in or out to vary the core length and measuring the detector output for various lengths and distances from an exciting source.

SEISMOGRAPH PROSPECTING

U. S. No. 2,374,204. H. Hoover, Jr. Iss. 4/24/45. App. 7/24/39. Assign. United Geophysical Co.

Apparatus for Recording Seismic Waves. An amplitude control for seismograph amplifiers in which the gain is initially set to an intermediate level subsequently reduced by avc action and finally allowed to recover to a higher than initial level by a delayed shot moment controlled switch of amplifier bias.

U. S. No. 2,375,283. R. T. Cloud. Iss. 5/8/45. App. 5/21/37. Assign. Stanolind Oil and Gas Co.

Amplification Control in Seismic Surveying. A condenser discharge type of expander for seismograph amplifiers which controls the grid bias of two tubes in push-pull so as to avoid zero drift of the galvanometer.

U. S. No. 2,375,433. J. P. Minton. Iss. 5/8/45. App. 3/29/43. Assign. Socony-Vacuum Oil Co., Inc.

Seismograph. A free timing reed for interrupting a light beam to produce timing lines on a seimograph record, the reed being given an impulse by an electro-magnet as the recording camera is started.

U. S. No. 2,375,570. E. McDermott. Iss. 5/8/45. App. 2/5/35. Assign. Geophysical Service, Inc.

Seismic Detector System. An expander for a group of seismograph amplifiers in which a spring drives attenuators to simultaneously reduce the attenuation in the channels with time after the shot moment.

U. S. No. 2,376,195. S. A. Scherbatskoy. Iss. 5/15/45. App. 9/15/36. Assign. Engineering Laboratories, Inc.

Amplifying Apparatus. An expander for seismograph amplifiers which varies the grid bias of two tubes in cascade to avoid zero drift of the galvanometer.

U. S. No. 2,376,730. J. R. Steinhoff. Iss. 5/22/45. App. 4/17/42.

Apparatus for Sonic Detection. A device for sonic detection using four microphones directed in a plane and a fifth microphone directed normal and connected so as to cancel local noise.

U. S. No. 2,377,212. R. B. Cottrell. Iss. 5/29/45. App. 12/30/43. Assign. American Steel Foundries.

Accelerometer. An accelerometer having a mass supported at its center of gravity by straps in three mutually perpendicular axes and strain gauges mounted on the straps to measure changes in tension.

U. S. No. 2,377,763. E. F. Darnell. Iss. 6/5/45. App. 8/31/42. Assign. Olive S. Petty.

Loading Basket for Explosive Charges. A basket for loading charges in seismograph shot holes and having one side open to prevent fouling the cap wires and a lug to engage a slot in the upper explosive shield so that the charge may be rotated as it is pushed down.

U. S. No. 2,377,804. P. E. Navarte. Iss. 6/5/45. App. 5/29/43. Assign. Olive S. Petty.

Blasting Cap. A blasting cap which eliminates danger of detonation by electrostatic discharge by having a high resistance conducting plug, or a very small air gap from wires to shell, or an ionized gas chamber, located above the bridge plug.

U. S. No. 2,377,903. F. Rieber. Iss. 6/12/45. App. 5/1/33. Assign. Continental Oil Co.

System for Geological Exploration by Elastic Waves. A seismograph prospecting system using a long horizontally extended shot or several parallel linear shots fired in timed sequence, together with a collinear geophone, the geophone and amplifying apparatus being designed to accentuate the onset of reflected events.

U. S. No. 2,378,223. J. B. Johnson. Iss. 6/12/45. App. 11/8/41. Assign. Hercules Powder Co.

Explosive Cartridge. A dynamite cartridge having two oppositely wound spiral lines of weakness so that when endwise pressure is applied it may expand to completely fill the shot hole.

U. S. No. 2,378,925. E. E. Hoskins and R. M. Moore. Iss. 6/26/45. App. 7/24/39. Assign. United Geophysical Co.

Seismic Prospecting System. An avc system for seismograph amplifiers using an expander or output signal controlled avc supplemented by a pair of copper oxide rectifiers to act as variable impedance shunts on the amplifier input.

U. S. No. 2,378,939. A. M. Nicolson. Iss. 6/26/45. App. 12/16/38 and 2/24/43.

Echo Sounding Apparatus. Wave detecting apparatus having one detector operating into two channels interconnected by a polarization cell so that an initially propagated signal in one channel renders the other operative for detecting an echo, or having two detectors with two channels interconnected by a polarization cell so that the first signal renders the other channel inoperative in order to determine wave direction.

WELL LOGGING AND SURVEYING

U. S. No. 2,372,875. R. Benke. Iss. 4/3/45. App. 6/6/44. Assign. The Atlantic Refining Co.

Coring Device. A mechanical side wall coring device having an electric motor which

rotates the core bit and simultaneously drives the core bit into the formation by means of an opposed thread driven toggle.

U. S. No. 2,373,061. F. J. Spang. Iss. 4/3/45. App. 1/24/42.

Device for Determining the Condition of a Well Bore from an Etched Acid Bottle. A calibrated sliding scale instrument which may be applied to an acid bottle etching to read off directly the angle, corrected vertical depth and distance of measured point from vertical.

U. S. No. 2,373,323. G. A. Macready. Iss. 4/10/45. App. 11/21/41.

Process and Apparatus for Pressure Core Drilling. A pressure core barrel in which contamination of the core is prevented by a seal of fusible alloy melted by heat of drilling and by receiving the core in a chamber filled with glycerine.

U. S. No. 2,373,976. L. Ranney. Iss. 4/17/45. App. 8/1/42.

Surveying Instrument. A device for surveying a well and having a floating bob and a floating compass each with pointed end pins which are caught in corks forced together by fluid pressure when the instrument is set for a reading.

U. S. No. 2,374,197. D. G. C. Hare. Iss. 4/24/45. App. 1/15/42. Assign. Texaco Development Corp.

Borehole Logging Method and Apparatus. A method of radioactivity well logging while drilling by means of an annular gamma ray detector just above the bit and connected to an indicator at the surface.

U. S. No. 2,374,557. C. V. Millikan. Iss. 4/24/45. App. 10/5/42. Assign. Geophysical Research Corp.

Oil Well Testing Device. A device for testing the flow from strata and having a flow displaced piston which scribes a record on a clock driven copper sheet.

U. S. No. 2,374,961. B. W. Sewell. Iss. 5/1/45. App. 12/21/39. Assign. Standard Oil Development Co.

Core Barrel. A wire line operated pressure core barrel which locks to the drill stem and is released and sealed by an upward pull.

U. S. No. 2,375,313. L. C. Miller. Iss. 5/8/45. App. 2/7/41. Assign. Eastman Oil Well Survey Corp.

Well Tool. An orienting tool for directional drilling apparatus having an eccentric weight which by gravity finds the low side of the hole and positions a shoe so that when fluid pressure is applied it forces a ball and socket mounted tool into the desired orientation.

U. S. No. 2,375,972. J. T. Wood and E. L. Davis. Iss. 5/15/45. App. 5/27/41. Assign. The Texas Co.

Formation Tester. A small diameter formation tester run on tubing and having a packer which is expanded when weight is applied by resting a perforated lower section on bottom.

U. S. No. 2,376,168. W. D. Mounce. Iss. 5/15/45. App. 10/19/38. Assign. Standard Oil Development Co.

Well Logging. A method of three electrode a-c resistivity well logging using a single conductor cable by supplying a-c current from the surface to the lower electrode and in the well apparatus rectifying and filtering the a-c picked up by two potential electrodes and transmitting the resulting d-c to the surface for measurement.

U. S. No. 2,376,196. S. A. Scherbatskoy. Iss. 5/15/45. App. 9/30/43. Assign. Well Surveys, Inc.

Ionization Chamber. A cylindrical ionization chamber for well logging whose outer electrode is made by painting the inside of the instrument housing with insulating varnish and applying a conducting coating of graphite or electroplated metal.

U. S. No. 2,376,610. J. W. Millington. Iss. 5/22/45. App. 12/12/41. Assign. Sperry-Sun Well Surveying Co.

Electrical Prospecting Method and Apparatus. A method of electrical logging in which the well apparatus has a high frequency oscillator inductively coupled to the formations and records both frequency variations and amplitude variations.

U. S. No. 2,376,821. S. A. Scherbatskoy, R. E. Fearon, J. Neufeld and G. Swift. Iss. 5/22/45. App. 9/15/41 and 5/22/43. Assign. Well Surveys, Inc.

Well Logging Instrument. A radiation logging instrument having a long cylindrical steel case which forms the ionization chamber and which has easily removable signal measuring and transmitting unit and power unit, signal transmission being over a single conductor cable.

U. S. No. 2,376,878. P. J. Lehnhard, Jr. Iss. 5/29/45. App. 6/15/41. Assign. The Dow Chemical Co.

Method of Determining the Permeability of Earth Formations. A method of determining permeability of well formations by introducing conducting fluid at the bottom through tubing which has a conductivity detector opposite the formation level, the annular space above it being filled with non-conducting fluid.

U. S. No. 2,377,501. M. M. Kinley. Iss. 6/5/45. App. 8/18/41.

Fluid Influx Indicator. A device which isolates the flow into the tubing from a region of the well by means of two packers and a by-pass and has an electrode for measuring the electrical conductivity of the isolated fluid.

U. S. No. 2,378,408. G. Herzog. Iss. 6/19/45. App. 9/30/42. Assign. The Texas Co.

Method and Apparatus for Logging Boreholes. Method and apparatus for radioactivity logging having both a long and a short radiation detector with a switch so that the long detector may be used for high speed and the short detector for slow speed and for detection of thin horizons.

U. S. No. 2,378,526. R. D. Agnew. Iss. 6/19/45. App. 4/8/42. Assign. Schlumberger Well Surveying Corp.

Well Surveying Instrument. A surface recording well surveying instrument having a pendulum-mounted light shining on a photocell through a screen with zones of different

transparency, and a second pendulum-mounted light shining on a photocell through a pivoted compass card screen with sectors of different transparency.

U. S. No. 2,379,045. H. F. Sturgis. Iss. 6/26/45. App. 5/29/41. Assign. Stanolind Oil and Gas Co.

Analyzing Earth Formations. A geochemical well logging method in which cuttings are analyzed for hydrocarbon and water content simultaneously by heating and collecting the vapors in a water-immiscible absorption medium.

U. S. No. 2,379,106. C. S. Sanders. Iss. 6/26/45. App. 8/30/41. Assign. Stanolind Oil and Gas Co.

Detecting Salt Water Intrusion. Detecting water intrusion by conditioning the well with nonconducting fluid, lowering a long uncovered resistance wire and noting the resistance when short circuit to ground first occurs or lowering a cable with electrodes across different impedances which will be short circuited by salt water.

U. S. No. 2,379,138. R. U. Fitting, Jr. and M. H. McKinsey. Iss. 6/26/45. App. 1/11/43. Assign. Shell Development Co.

Annular Flow Measuring Device. A method and apparatus for measuring the flow in the annular space in a well by pumping liquid to the bottom and having packers with flow meters at spaced intervals up the hole, operation of the flow meters being detected by an acoustic or electromagnetic detector lowered through the tubing and recording at the surface.

MISCELLANEOUS

U. S. No. 2,372,757. W. O. Bennett, Jr. Iss. 4/3/45. App. 12/19/41. Assign. Hamilton Watch Company.

Timing Device. A watch or clock rate checker having a stepping switch actuated by amplified tick impulses, the switch starting a standard electric timer and stopping it after a predetermined number of ticks.

U. S. No. 2,372,810. M. Camras. Iss. 4/3/45. App. 10/14/42. Assign. Armour Research Foundation.

Constant Speed Drive for Magnetic Recorders. A magnetic tape drive in which the tape makes several loops around a pulley driving a flywheel each loop passing around idlers, recording being done on one of the loops.

U. S. No. 2,373,096. R. K. Bonnell. Iss. 4/10/45. App. 12/15/41. Assign. Sperry Gyroscope Co., Inc.

Magnetic Pick-Off for Sensitive Instruments. A device for repeating the indication of a sensitive instrument without reacting upon it by having a magnet on the instrument and picking up the orientation of the magnet from the non-linearity in periodically excited high-permeability cores affected by the magnet.

U. S. No. 2, 373,151, D. D. Taylor. Iss. 4/10/45. App. 7/29/42. Assign. Consolidated Engineering Corp.

Analytical System. A method of analyzing a mixture with a mass spectrometer by

operating at an ionization voltage intermediate between the appearance potentials of an ion for two components.

U. S. No. 2,373,180. F. J. Faltico. Iss. 4/10/45. App. 1/6/44. Assign. The Maico Co., Inc.

Automatic Volume Control Circuit. An avc applicable to audio circuits and in which a grid of one tube operates as an anode, its plate being connected to the plate of the next stage so that when the latter exceeds a threshold the plate draws current and increases grid bias.

U. S. No. 2,373,273. G. C. Sziklai. Iss. 4/10/45. App. 10/28/42. Assign. Radio Corp. of America.

Signal Recording and Reproducing Methods. A method of recording on a moving metallic tape by passing signal current through a restricted area having contact with an electrolytic solution so as to form a dielectric film whose thickness varies with signal.

U. S. No. 2,373,846. H. Olken. Iss. 4/17/45. App. 8/2/41.

Method and Apparatus for Moisture Measurement of Materials. A method of electrical testing of material by placing it between the plates of a condenser in an oscillating circuit, the dimensions and frequency being adjusted for optimum sensitivity.

U. S. No. 2,374,205. E. E. Haskins. Iss. 4/24/45. App. 7/3/43. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A safety device for protecting a mass spectrometer from flashover and high pressure contamination by automatically cutting off the supply of filament current and accelerating potential.

U. S. No. 2,374,512. W. D. Van Dyke. Iss. 4/24/45. App. 7/26/43. Assign. Douglass Aircraft Co., Inc.

Machine for Making Strain Gauges. A jig for forming filament type strain gauges with several loops.

U. S. No. 2,375,022. G. V. Morris and R. Adler. Iss. 5/1/45. App. 11/11/41. Assign. Associated Research, Inc.

Instrument for Testing Grounding Resistance. An a-c circuit for testing apparatus grounds in which current is passed through the ground and a potentiometer in series, and the grounding resistance drop balanced out.

U. S. No. 2,375,892. G. Bouyoucos. Iss. 5/15/45. App. 5/13/43. Assign. Michigan State Board of Agriculture.

Thermometer. An electrical resistance thermometer made by sealing two electrodes into a non-conducting container and filling with a non-electrolytic liquid so as to completely cover the electrodes.

U. S. No. 2,376,311. R. L. Hood. Iss. 5/15/45. App. 3/21/42. Assign. American Cyanamid Company.

Photoelectric Recording System. A recording infrared spectrophotometer having a photoelectric recording system in which galvanometer deflection varies the amount of

light falling on a photocell and the illumination is corrected by a follow up system also driving the recording pen.

U. S. No. 2,376,877. R. V. Langmuir. Iss. 5/29/45. App. 5/25/42. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A system for automatically recording a mass spectrogram and which moves ion beams transversely across the collector slit at a speed which varies inversely with the mass-charge ratio by varying the magnetic field or the accelerating voltage.

U. S. No. 2,377,757. H. L. Clark. Iss. 6/5/45. App. 12/1/43. Assign. General Electrical Co.

Short Time Interval Meter. A time interval meter in which a condenser is charged during the interval and the terminating voltage measured, the condenser being started with an initial charge and charged at a regulated uniform rate.

U. S. No. 2,378,219. D. G. C. Hare. Iss. 6/12/45. App. 5/29/40 and 11/16/43. Assign. The Texas Co.

Method and Apparatus for Determining Liquid Level. A method of locating the liquid level through the wall of a closed container by moving vertically on the outside a source of fast neutrons together with a detector of scattered slow neutrons.

U. S. No. 2,378,383. J. P. Arndt, Jr. Iss. 6/19/45. App. 10/17/42. Assign. The Brush Development Co.

Transient Signal Recording-Reproducing Device. A multichannel transient recorder having a single continuously running endless magnetic tape with a recording head and an erasing head, the signals modulating recordable carrier waves which are later separated by filters on playback, and having automatic control to turn off the erasing head on arrival of a transient and turn off the recording head a fixed time thereafter.

U. S. No. 2,378,388. S. J. Begun. Iss. 6/19/45. App. 1/1/42. Assign. The Brush Development Co.

Recording and Reproducing Device. A transient recorder having a continuously running endless magnetic tape with a recording head and an erasing head, and which automatically turns off the erasing head on arrival of a transient and turns off the recording head a fixed time thereafter.

U. S. No. 2,378,389. S. J. Begun. Iss. 6/19/45. App. 11/26/42. Assign. The Brush Development Co.

Recording-Reproducing Device. A multichannel transient recorder having a single continuously running endless magnetic tape, the recording and erasing heads for the channels distributed along the tape, and a trigger control which turns off the erasing heads on arrival of a transient and turns off the recording heads in time to prevent overlapping of records.

U. S. No. 2,378,491. B. F. McNamee. Iss. 6/19/45. App. 4/18/44. Assign. The Superior Oil Company.

Viscosimeter. A device for continuously indicating the viscosity of drilling mud by

flowing part of the mud through an orifice and part through a tube and indicating the difference in the flows by paddle meters differentially coupled to a pointer by magnetic drag.

U. S. No. 2,378,936. R. V. Langmuir. Iss. 6/26/45. App. 7/15/43. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A recording mass spectrometer having a decaying accelerating voltage beam sweeper and a d-c amplifier connected to a known step of the accelerating voltage for controlling relays which switch the potentiometer step and record the ion mass on the record as the proper voltage is passed.

U. S. No. 2,378,962. H. W. Washburn. Iss. 6/26/45. App. 12/9/43. Assign. Consolidated Engineering Corp.

Mass spectrometry. A mass spectrometer in which the analyzer, electrodes and ionization chamber are made of polished non-porous metal and having heating coils to maintain a temperature of 200°C.

U. S. No. 2,379,282. R. Dally, F. H. Goldsmith and D. J. Munroe. Iss. 6/26/45. App. 8/7/43. Assign. Webster Electric Co.

Recorder. A phonograph record cutter of the permanent magnetic bridge type in which the stylus-carrying armature is a high frequency reed.

PUBLICATIONS RECEIVED

(The publications listed below were received since issuance of GEOPHYSICS for July, 1945, and are available for loan to the membership. Articles cited are those of particular interest to geophysicists).

American Journal of Science, Vol. 243, Nos. 5, 6, 7, 8, 9 (May to September, 1945), New Haven.

Bulletin de l'Academie des Sciences de l'Union des Republiques Sovietiques Socialistes. Serie geographique et geophysique. Moscow. Vol. VIII, Nos, 5, 6 (1944), Vol. IX, No. 1 (1945). Articles are in Russian, with English summaries:

No. 5 (1944)

"Geophysical Prospecting for Oil in the USSR at the Time of Patriotic War (1941–1943)," by V. V. Fedynsky, pp. 229–243.

"Experiment of Application of the Hypothesis of Partial Isostatic Compensation," by D. N. Khramov, pp. 281–284.

"On the Accuracy of the Measurements of the Anomaly of Gravitation with the Aid of Gravitational Variometers," by J. Boulanger, pp. 285–291.

"Direct and Inverse Problem of the Magnetic Potential for a Spheric Segment," by I. S. Gelfand, pp. 292–294.

"The Inverse Problem of the Gravitational Potential for the Homogeneous Ellipsoid Generated by Rotation," by I. S. Gelfand, pp. 295–297.

No. 6 (1944)

"On the Addition of Oscillations of Two Gravimetrical Pendula on a Ship," by V. A. Kasinsky, pp. 381–384.

"Determination of the Magnetic Field of the Earth Acting in Different Geological Epochs," by O. N. Althansen, pp. 385–392.

No. 1 (1945)

"To the Development of the Theory of the Method of Well Seismographs," by G. V. Risnichenko, pp. 10–20.

"Hodographs of Reflected Waves and Their Interpretation at the Presence of a Horizontal Gradient of Velocity," by I. S. Berson, pp. 21–35.

"On the Velocity of the Propagation of Sound in Oil Wells," by A. J. Lisjutin, pp. 40–48.

"On the Influence of Variations in the Motion of the Chronometer in Carrying Out Pendulum Observations," by J. D. Boulanger, pp. 49–62.

Bureau of Mines Information Circular No. 7323 (June, 1945), "Bibliography of Russian Literature on Geophysical Exploration, 1929–1941."

Bureau of Mines Information Circular No. 7324 (June, 1945), "Geophysical Abstracts 120, January–March, 1945."

Bureau of Mines Report of Investigations No. 3810 (May, 1945), "Magnetic Survey of the Florida Peninsula," by F. W. Lee, J. H. Swartz, and S. J. Hemberger. (See review in this issue, page 547.)

Bureau of Mines Report of Investigations No. 3814 (June, 1945), "Magnetometer Surveys on Black Sands of the Oregon Coast," by E. L. Stephenson.

Cambridge Philosophical Society, Proceedings, Vol. 41, Part 1, (June, 1945).

Economic Geology, Vol. XL, Nos. 2, 3, 4, 5 (March–April, May, June–July, August, 1945).

Independent Petroleum Association of America Monthly, The, Vol. 16, Nos. 3, 4, 5 (July, August, September, 1945).

Journal of Applied Physics, Vol. 16, Nos. 5, 6, 7 (May–July, 1945).

Journal of the Institute of Petroleum, Vol. 31, Nos. 256, 257, 258, 259, 260 (April–August, 1945).

Mining and Metallurgy, Vol. 26, No. 465, (September, 1945).

Petroleum, Vol. VIII, Nos. 5, 6, 8 (May, June, August, 1945).

Publicaciones del Instituto de Fisiografia y geologia; Rosario, Argentina.

Review of Scientific Instruments, The, Vol. 16, Nos. 4, 5, 6, 7, 8 (April–August, 1945), "Mercury Jet Magnetometer" (August, 1945).

Terrestrial Magnetism and Atmospheric Electricity, Vol. 50, No. 2 (June, 1945)

"The Gulf Absolute Magnetometer," by Victor Vacquier, pp. 91–104.

"The Geographic Incidence of Aurora and Magnetic Disturbance, Southern Hemisphere," by E. H. Vestine and E. J. Snyder, pp. 105–124.

"The Comparison of Horizontal-Intensity Magnetometers," by A. Ogg, pp. 125–130.

"Magnetic-Activity Indices, January to March, 1945," by H. F. Johnston, pp. 131–134.

World Petroleum, Vol. 16, Nos. 5, 6, 7, 8, 9 (May–September, 1945).

"Exploratory Drilling in 1944," by H. F. Lahee. (June).

"World's Oil Position as War Ends." (September)

CONTRIBUTORS

Roy L. Lay received his B.S. degree in Electrical Engineering from Rice Institute in 1928. He was employed by the Geophysical Research Corporation from 1928 to 1932, acting in various capacities on both refraction and reflection crews. In 1932 Mr. Lay accepted a position with The Texas Company, by whom he is still employed as Assistant Chief of the Geophysical Division. Since joining The Texas Company Mr. Lay has been in charge of various geophysical field operations in this country as well as certain foreign operations. He is a member of the American Association of Petroleum Geologists, Houston Geological Society and the Society of Exploration Geophysicists.

ROY L. LAY

LEO HORVITZ

Leo Horvitz received the degree of Sc.B in Chemistry from Brown University in 1931 and the Sc.M. degree from the same institution in 1932. In 1935, he received the degree of Ph.D. in Chemistry from the University of Chicago.

With the exception of eight months spent in War Research during 1942–43, he has been continuously active, since 1936, in the development and application of geochemical prospecting methods. From 1936 to 1941, he was chief research chemist for Subterrex. In 1941, he entered into consulting work and in 1942 organized the Horvitz Research Laboratories specializing in the application of geochemical prospecting methods.

He is a member of the American Chemical Society, the Society of Exploration Geophysicists, the American Association of Petroleum Geologists, the American Association for the Advancement of Science, and the American Geophysical Union.

ROBERT S. DAHLBERG, JR.

Robert S. Dahlberg, Jr., received his B.A. and M.A. degrees from the University of Texas. He has been engaged in geophysical exploration work in the field and in the laboratory for thirteen years; and is at present employed in the laboratories of the Carter Oil Company at Tulsa, Oklahoma. He is a member of the Society of Exploration Geophysicists and of the American Geophysical Union.

W. Bernard Robinson received the degree of B.S. in E.E. from the University of Nebraska in 1930. From 1930 to 1933 he was employed by the Westinghouse Electric & Mfg. Co. For the past 12 years he has done seismograph interpretation work with the Gulf Research & Development Company. He is a member of the A.A.P.G., S.E.G., and the Pittsburgh Geological Society.

W. BERNARD ROBINSON

Photographs and biographies of contributors to this issue not appearing above have been published previously, as follows: W. K. Hastings, Vol. X, No. 1, p. 120, (January, 1945), H. Klaus, Vol. VIII, No. 4, p. 436, (October, 1943), E. J. Stulken, Vol. VI, No. 4, p. 463, (October, 1941).

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Richard Newbold Bruyere
L. A. Scholl, Jr., R. L. Lay, C. R. Wallace

Paul Jacques Daniel Charrin
E. D. Williams, J. Brian Eby, Paul Weaver

Monroe George Cheney
J. Brian Eby, John S. Ivy, Paul Weaver

George Bryan Clark
H. M. Falkenhagen, H. H. Jones, R. T. Penny

Rollin Earl Davis
Sidon Harris, Gwendolyn Peabody, Paul H. Ledyard

Herbert Marion Dawson
W. Harlan Taylor, O. S. Petty, Thomas L. Allen

Henry Faul
(III-D-1 of the Constitution)

Melvin Miller Garrett
Cecil H. Green, Henry C. Cortes, Maynard P. Jones

Harold Edwin Granberry
W. B. Raper, A. F. Dugan, Glen M. McGuckin

Bernardo Grossling
C. Hewitt Dix, Beno Gutenberg, Lawrence K. Morris

Frederick William Hales
T. C. Richards, R. Davies—III-D-1 of the Constitution

Travis Orville Harkness
Leslie C. Spencer, W. B. Hogg, C. G. McBurney

Bruce Martin Jennings, Jr.
Henry C. Cortes, W. B. Raper, Robert L. Tucker

Henry Rochambeau Joesting
J. H. Swartz, Joseph A. Sharpe, C. A. Heiland

Howard LeVasseur Kipfer
L. F. Athy, J. M. Crawford, A. F. Haber

Charles Cobleigh O'Boyle
W. S. Levings, L. F. Athy, C. A. Heiland

Helen Violet Officer
J. E. Hawkins, G. H. Westby, Stanley W. Wilcox

Franklin H. Schouten
R. Clare Coffin, Sidon Harris, Paul H. Ledyard

Raymond Albert Stehr
Cecil H. Green, Henry C. Cortes, E. S. Sherar

Leslie Hamilton Tarrant
R. Davies, T. C. Richards—III-D-1 of the Constitution
Emile Jean Paul Van der Linden
A. J. Barthelmes, G. H. Westby, J. E. Hawkins
Edward Joseph Walter
F. Goldstone, L. K. Mower, L. E. Deacon

ASSOCIATE

Sylvio Fróes Abreu
Lewis MacNaughton, Henry C. Cortes, W. R. Ransone
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Carl James Chapman
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William Robertson Doll
Albert J. Barthelmes, J. L. Kezeler, H. M. Thralls
William Logan Foote
Frank Ittner, L. B. Trombla, J. E. Stones
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George Burton MacSween
R. Maurice Tripp, Roland F. Beers, C. L. Doss
Carter Pickring Porter
J. W. Thomas, Cecil H. Green, M. C. Kelsey
Wesley Noel Rabey
F. A. Roberts, J. D. Berwick, Dr. J. C. Sproule

TRANSFER TO ACTIVE MEMBERSHIP

W. Wise Hollingsworth
V. J. Mercier

PRELIMINARY ANNOUNCEMENT OF THE SIXTEENTH ANNUAL MEETING OF THE SOCIETY

The Society of Exploration Geophysicists will meet with the American Association of Petroleum Geologists and the Society of Economic Paleontologists and Mineralogists in Chicago, the first week of April, 1946. The Stevens Hotel will be headquarters for all three societies. Dr. J. J. Jakosky, Vice-President of the S.E.G., is General Chairman of the Program and Arrangements Committee. Regional and special committees will be named and published later.

Present plans call for the usual annual business meeting of the S.E.G. on Monday, April 1, followed by technical sessions Monday morning and afternoon, a joint meeting with the A.A.P.G. Tuesday morning, and a technical session Tuesday afternoon. This will allow time for some twenty-five or thirty papers.

Members of the Society should begin now to make plans for papers to be presented in person or read by title at the meeting. If you plan to have a paper or know of someone who has good material for a paper, you will help the Society by sending such information to Dr. J. J. Jakosky, 1063 Gayley Avenue, Los Angeles 24, California.

PERSONAL ITEMS

E. DARRELL WILLIAMS, formerly with Universal Exploration Company, has opened an independent office for seismic interpretations at 2732 Pittsburg Street, Houston, Tex.

CLAUDE WENDELL HORTON, recently with the Underwater Sound Laboratory, Harvard University, may now be addressed at 1421 Scharpe St., Houston, Tex.

R. H. TALLMAN is with the Tropical Oil Company, Bogotá, Colombia.

JOSEPH R. GOBERNA, S.J., who for some time past has been at St. Louis University, is now on the staff of the Colegio de Belen, Aptdo. 221, Havana, Cuba.

JOHN M. NASH, until recently Major Nash of the U. S. Army, is now with the Shell Oil Company's Exploration Department, Mayo Building, Tulsa, Okla.

ROBERT W. JONES has transferred from Lovington, New Mexico, to the Gulf Research & Development Co., Box 2038, Pittsburgh, Pa.

W. L. IRBY, formerly at Tulsa, Oklahoma, is now in Colombia with The Tropical Oil Company. His address is Aptdo. Aereo 3533, Bogotá, Colombia.

ARNE JUNGER, seismologist with the Shell Oil Company, has been transferred from Bakersfield, California, to the Shell Company of Canada, Bank of Toronto Bldg., Calgary, Alberta, Canada.

R. G. SOHLBERG, until recently with the Richmond Petroleum Company of Colombia, at Bogotá, has transferred to the Richmond Exploration Company of Venezuela, at Caracas, where he may be addressed at Tienda Honda a Puenta 61.

MISS RUTH BREEDLOVE, a recently welcomed member of the Society, is now computer for an Atlantic Refining Company geophysical crew at Sonora, Tex.

R. F. BENNETT has left the Independent Exploration Company, after nearly 13 years, to accept the position of division geophysicist in the Gulf Coast for the Sohio Petroleum Company. His address is 255 Mellie Esperson Bldg., Houston, Tex.

O. T. LAWHORN resigned as party chief for Geophysical Service, Inc., at Dallas, and is now geophysicist for Pan American Production Company, 1248 Mellie Esperson Bldg., Houston, Tex.

J. W. HORN, who has been with the Arkansas Louisiana Gas Company for several years, has joined the Garrett Exploration Company, 7015 Hillcrest Ave., Dallas, Tex.

HUBERT GUYOD, well logging consultant, has opened offices at 730 First National Bank Bldg., Houston, Tex.

DR. S. STEWART WEST left the Stanolind Oil Company at Tulsa, Oklahoma, and is now assistant professor in the Physics Department of the University of Alaska, at College, Alaska. He has bought land near Fairbanks, and plans to engage in farming there.

G. W. T. BARNETT is with the Anglo-Iranian Oil Co., Ltd., at Abadan, South Iran.

KIRBY J. WARREN, seismic computer with the Carter Oil Company, has been transferred from Forest, Miss., to Rawlins, Wyoming. His address there is Box 503.

JAMES B. MACELWANE, S.J., whose address was erroneously given in the April issue as 15 N. Grand Blvd., should be addressed as Dean of the Institute of Geophysical Technology, 3621 Olive St., St. Louis 8, Mo.

T. R. SHUGART has returned from Cambridge, Massachusetts, and is again with the Geotechnical Corporation at 1702 Tower Petroleum Bldg., Dallas, Tex.

JAMES A. SMITH may now be addressed at Aptdo. Aereo 465, Barranquilla, Colombia.

MAJOR DANIEL F. ELAM, of Duncan, Oklahoma, formerly with International Geophysics, Inc., and Halliburton Oil Well Cementing Co., was killed in action September 17, 1944, over Holland. He was liaison officer of a troop-carrier group which flew paratroopers into the initial attack against the Siegfried line.

M. KING HUBBERT, who joined the Shell Oil Company organization as geophysicist in the Texas Gulf area in 1943, has recently been named Associate Director of Exploration and Production Research, with offices in Houston. Before joining the Shell organization, Mr. Hubbert was Chief of the Mineral Resources Unit, Supply and Resources Division of the Board of Economic Warfare, at Washington, D. C.

V. L. JONES has resigned from the Stanolind Oil & Gas Company to become associated with Geophysical Development Corporation, and C. H. Frost Gravimetric Surveys, Inc., at 1242 South Boston, Tulsa, Okla.

J. F. GALLIE, who recently resigned as business manager of this Society, has also resigned his position as senior geologist of the Arkansas Oil and Gas Division at El Dorado, Arkansas, to accept the position of geologist with the Cabot Carbon Company of Pampa, Texas. His new address is Box 1101, Pampa, Tex.

LT. CMDR. JOHN H. CROWELL, USNR, was recently assigned to duty in the Pacific area. He may still be addressed at 5510 Brite Dr., Bethesda, Md.

R. L. MIMS has left the U.S. Coast Guard Operating Base at Mobile, Alabama, and is now at 5549 Cameron Blvd., Apt. B, New Orleans, 19, La.

FRANCIS A. ROBERTS has moved from Saskatoon to Wainwright, Alberta, Canada. His address is Box 87.

W. W. BUTLER, formerly with Superior Oil Co. at Alva, Oklahoma, is now with Tide Water Associated Oil Co., Box 1404, Houston, Tex.

LT. COL. JOHN V. LONG has been transferred from Fort Ord, California, to the Inspector General's Department, Washington 25, D. C.

E. E. CONANT is now located at 1514 Ave L, Lubbock, Tex.

DONUIL HILLIS has moved from San Francisco to 649 South Olive St., Los Angeles, Cal.

WARREN H. SMITH has changed his address from Brawley, California, to Room 109, 929 So. Broadway, Los Angeles.

CAPT. JOSEPH G. HATHAWAY has been transferred from Peterson Field, Colorado, to Biggs Field, El Paso, Tex.

ELECT. LT. G. R. JOHNSON, RCNVR, writes from aboard HMCS Prince Robert that mail is most likely to reach him at his home address, 344 37th Ave. West, Calgary, Alberta, Canada.

HAROLD W. WASHBURN, Director of Research for Consolidated Engineering Corpn. has changed his address from 595 E. Colorado St. to 620 North Lake Ave., Pasadena 4, Cal.

R. H. WOODWARD has moved from Belmont, Mass., to 12 Wendell St., Apt. 16, Cambridge, Mass.

F. W. OUDT has left Saginaw, Michigan, and is now addressed at Box 2099, Houston Tex.

GORDON B. HANCHEY, a recently enrolled member, is with the Western Geophysical Co., Box 464, Woodville, Miss.

R. G. PIETY has left the Farrand Optical Co. of New York, and is now at 504 Cherokee Ave., Bartlesville, Okla.

H. G. OWENS of Phillips Petroleum Company is now at New Castle, Wyoming.

HOLLOWAY FROST has returned from Caracas, Venezuela, and may be addressed at 728 Elizabeth St., Corpus Christi, Tex.

PAUL H. LEDYARD is with Southern Geophysical Co., Sinclair Bldg., Ft. Worth, Tex.

P. H. MINTZ is now in the Geophysical Department of Sun Oil Co. at Beaumont, Tex.

D. W. ST. CLAIR, with DeGolyer & MacNaughton of Dallas, is now stationed at Midland, Tex., Box 51.

C. L. DOSS has moved from Dallas to 149 Sidney St., Cambridge, Mass.

EUGENE WIANCKO is chief computer for United Geophysical Company at Bakersfield, California, Box 1564.

R. M. BRADLEY is with Cities Service Oil Co. at 413 Masonic Bldg., Bartlesville, Okla.

DR. SIDON HARRIS has recently been named President of Southern Geophysical Company, with main offices located in the Sinclair Building, Fort Worth, Tex. Dr. Harris has been associated with the geophysical industry for the past twelve years, ten of which were with the Stanolind Oil and Gas Company. During recent months, Dr. Harris has been a consulting geophysicist. Dr. Harris holds B.A., M.A., and Ph.D. de-

grees from the University of Texas, majoring in physics and minoring in mathematics and geology.

PAUL H. LEDYARD, who has his M.A. degree from the California Institute of Technology and who has been associated with Stanolind for the last ten years, has been named Seismograph Supervisor for Southern Geophysical Company. His mailing address will be in care of the company, 1003 Sinclair Bldg., Fort Worth 2, Tex.

JOHN L. ALBER is head of the Geophysical Department for International Petroleum Company in Peru. He has been in South America more than four years, and regrets having lost contact with so many of his seismograph associates. His address is care of International Petroleum Company, Geophysical Dept., Negritos via Talara, Peru, South America.

GEORGE N. MEADE, until recently Lieutenant Meade, may now be reached at 3614 Josephine St., Denver, Colo.

MAJOR LYNN D. ERVIN, USMCR, was on leave in August, but expected to be assigned overseas at an early date. His mail address is Route 2, Box 70, Glenwood Springs, Colo.

LEWIS H. BOYD, geophysicist with the Brown Geophysical Company of Houston, is now with the southeastern division of that company, at P.O. Box 724, Tallahassee, Fla.

JAMES E. MAKITCHIS, Party Chief of the E. V. McCollum Geophysical Company, is in Evergreen, Ala., P.O. Box 266.

Readers of GEOPHYSICS may be interested in recent applications of the same principles as those of reflection shooting but on a microscopic scale, whereby supersonic waves reveal flaws in solids by reflections from any discontinuity within the metal or other material being tested. A thin quartz crystal is driven at a frequency of the order of 5 megacycles in short pulses; the reflections are picked up by the same crystal and shown on a cathode-ray oscilloscope. The general principles and a number of examples of oscilloscope pictures are given in *Metal Progress*, Vol. 48, No. 3 (September, 1945), pp. 505–516.

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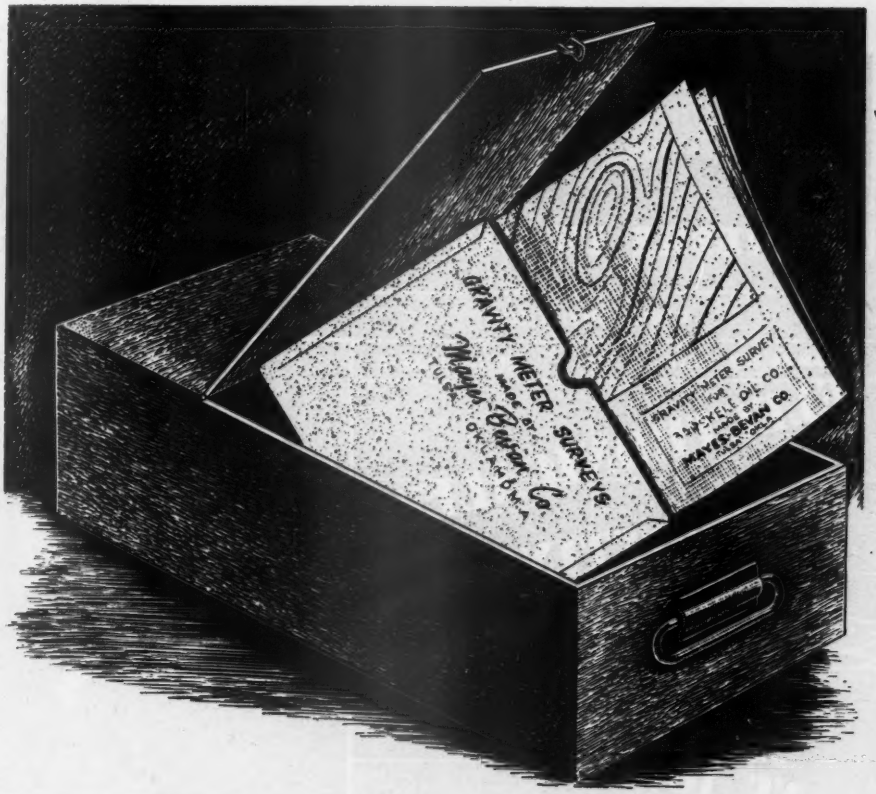

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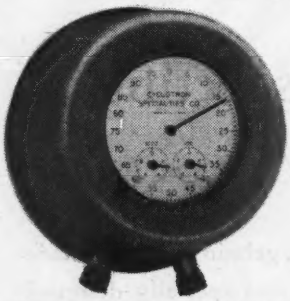

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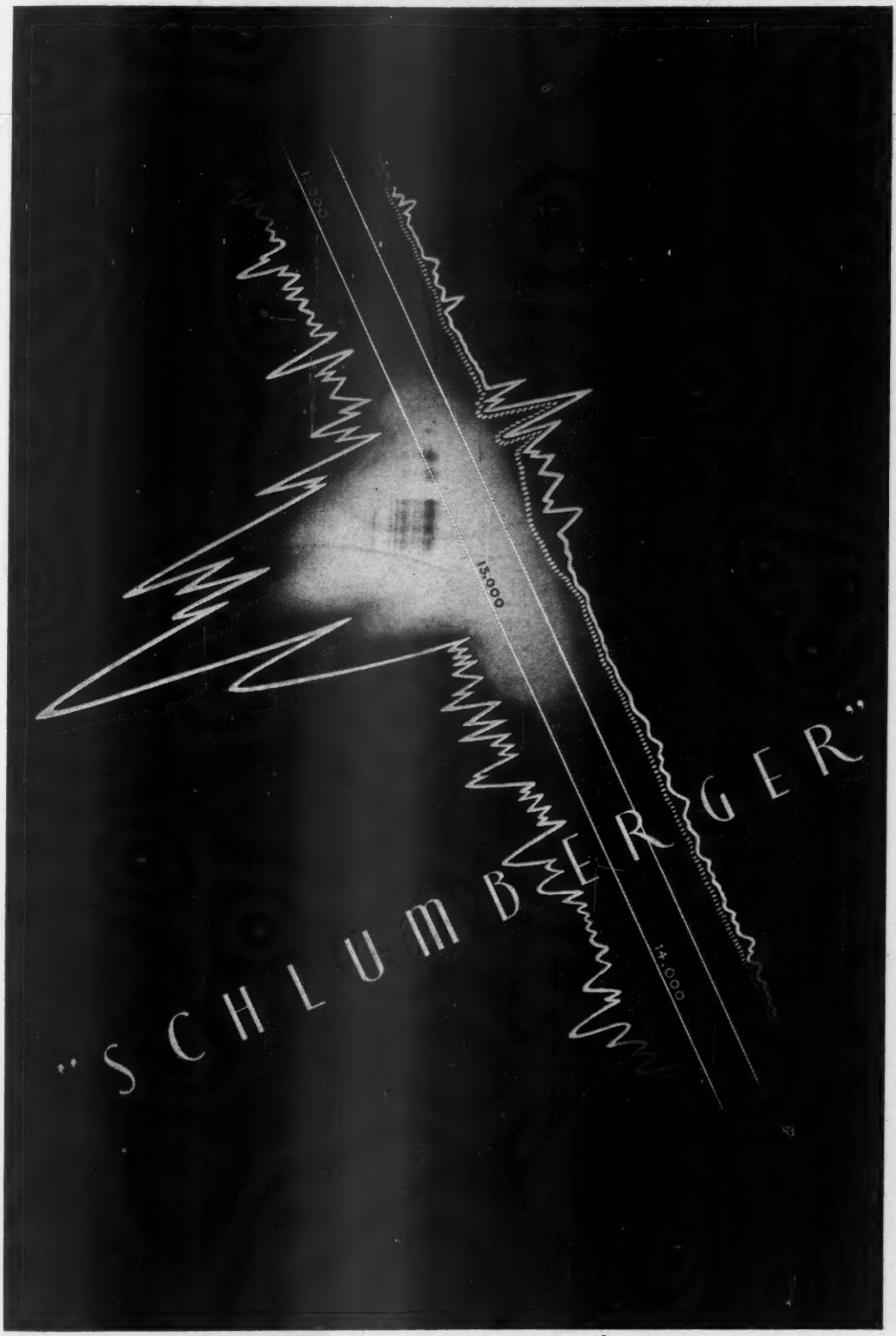
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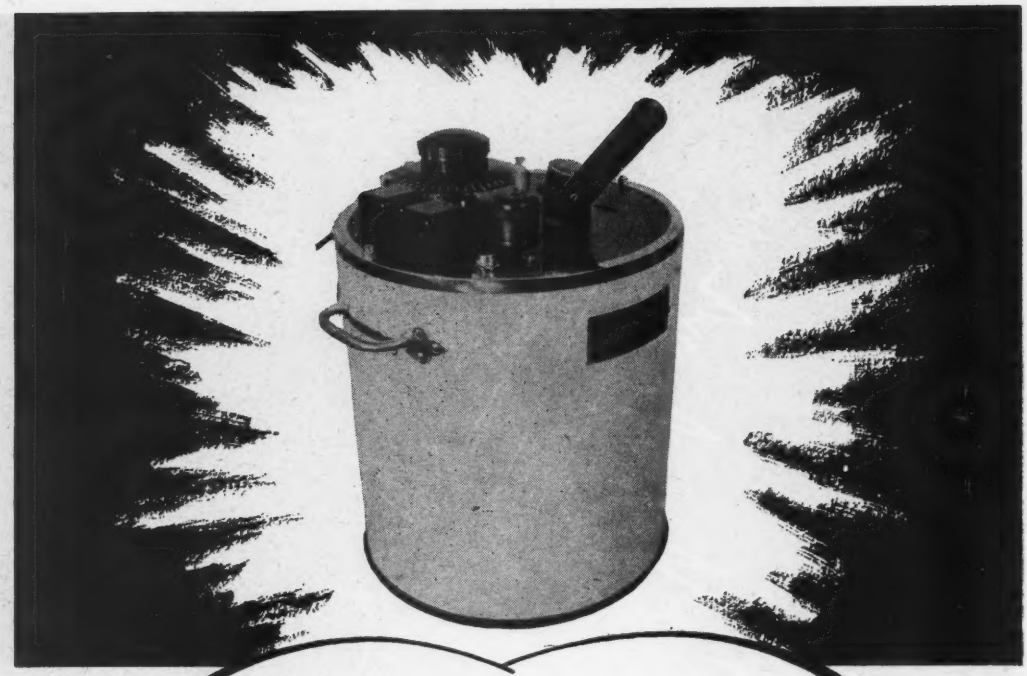

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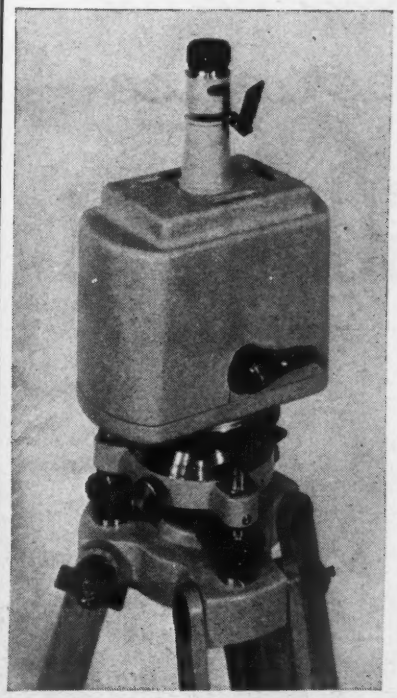

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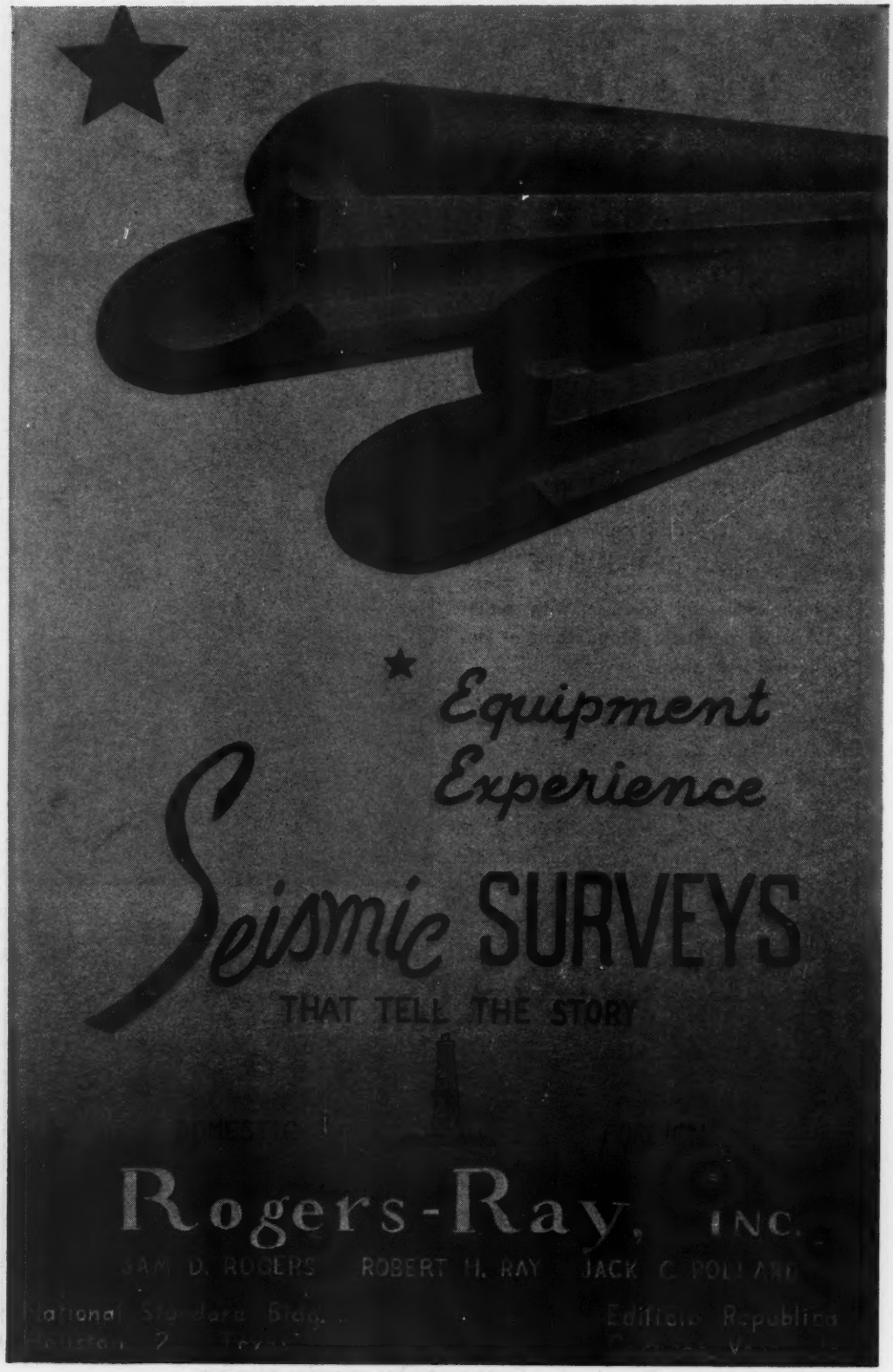
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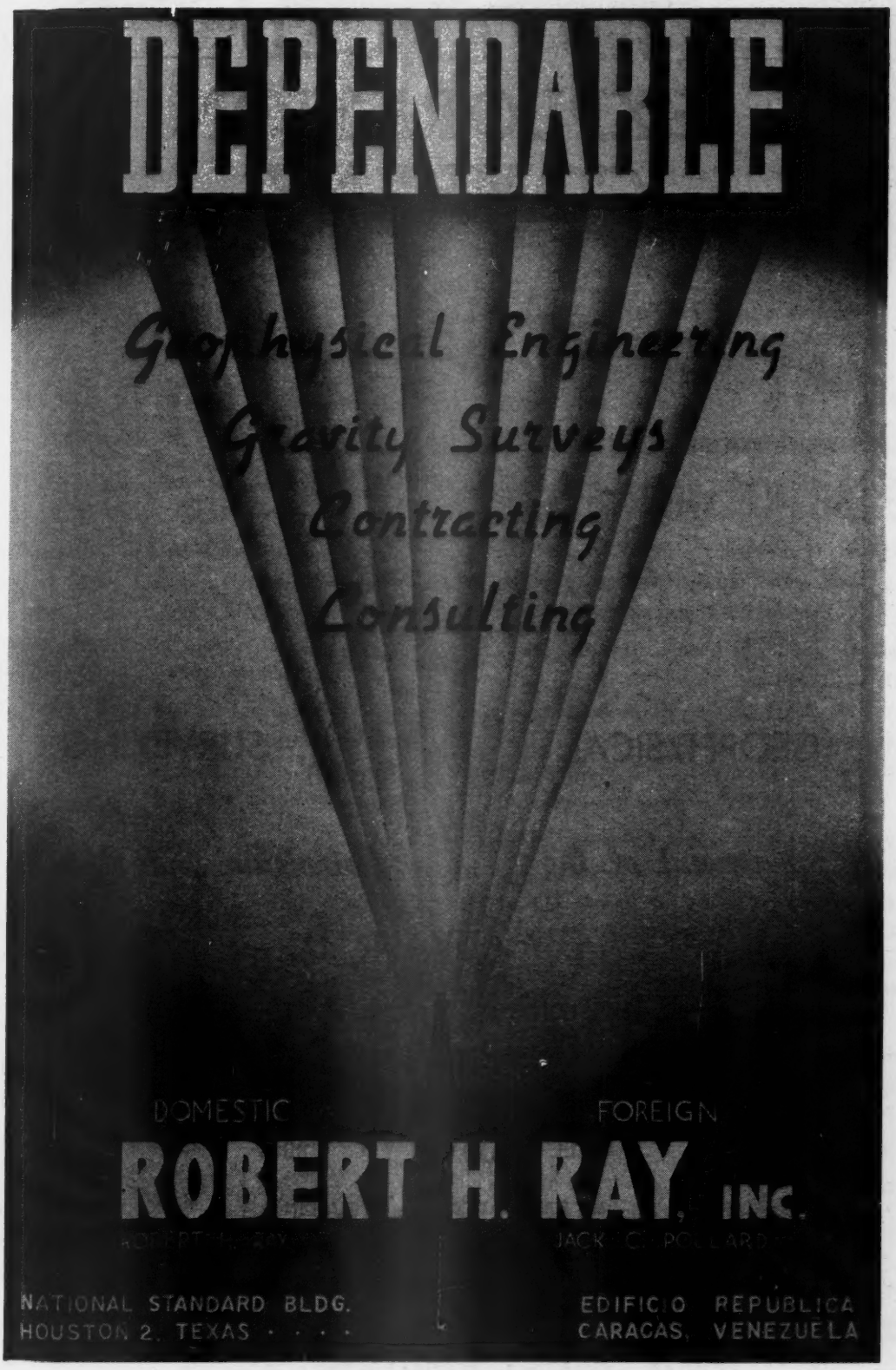
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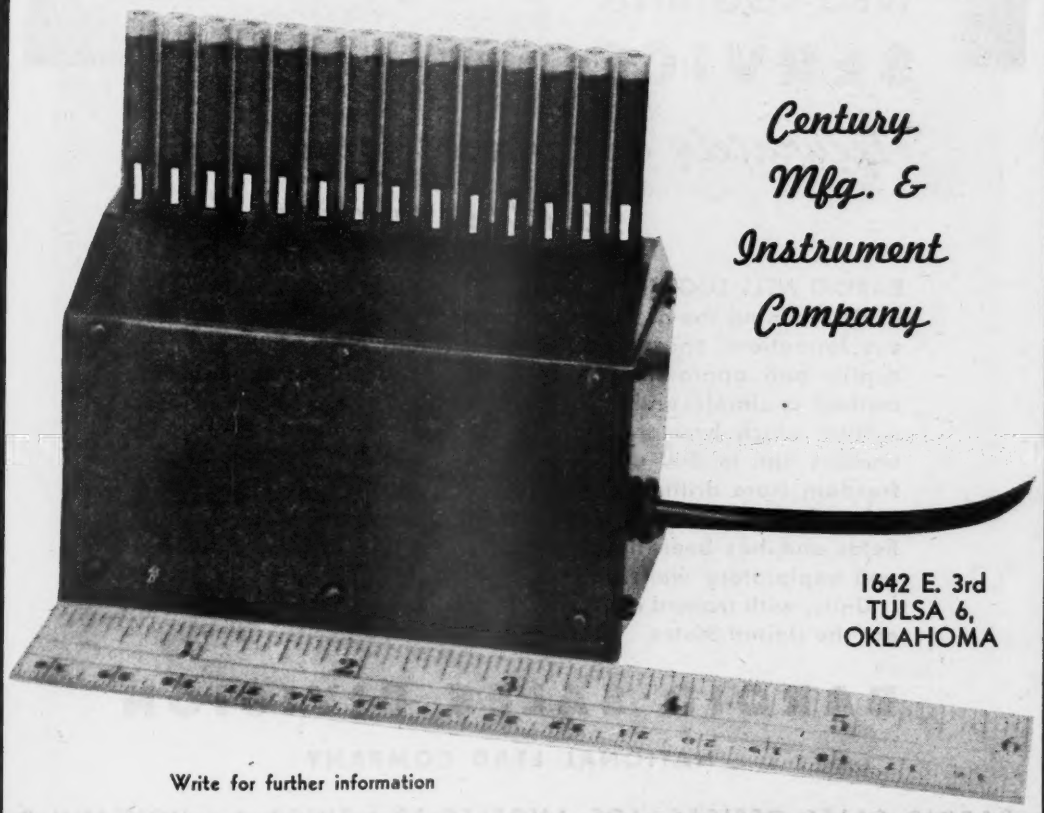

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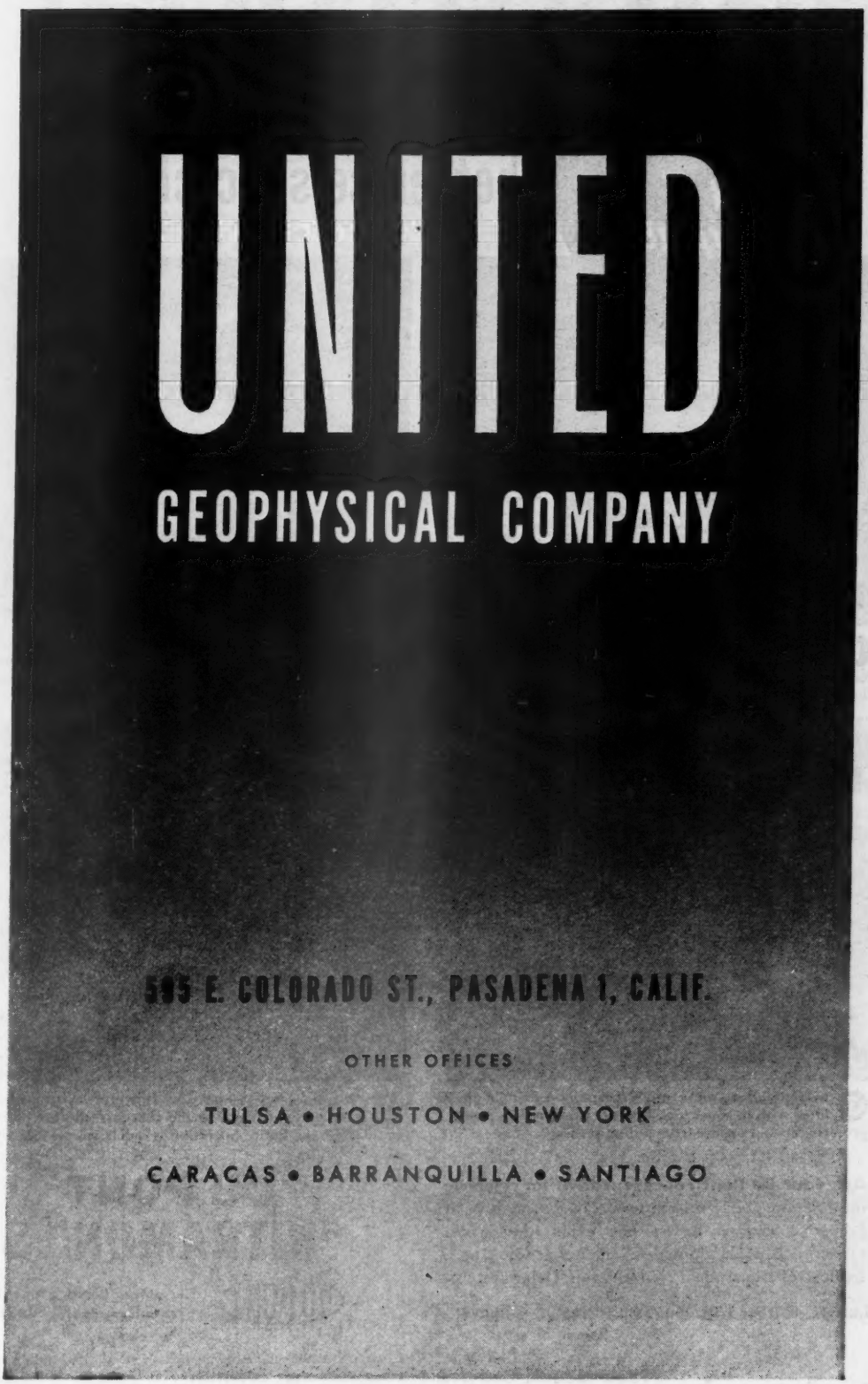
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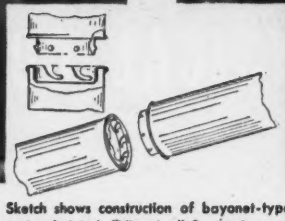
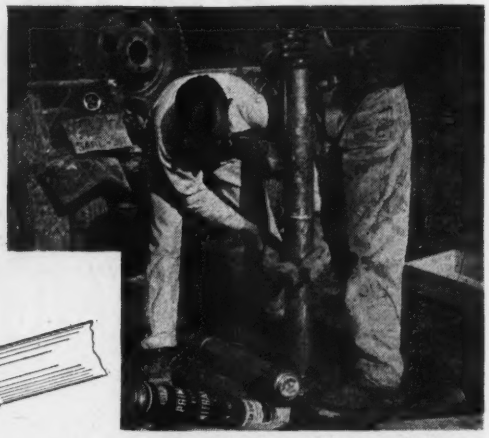


Sketch shows construction of bayonet-type ends of 4-inch "Nitramon" S containers. A twist of the wrists couples containers together ... makes a strong, rigid charge.



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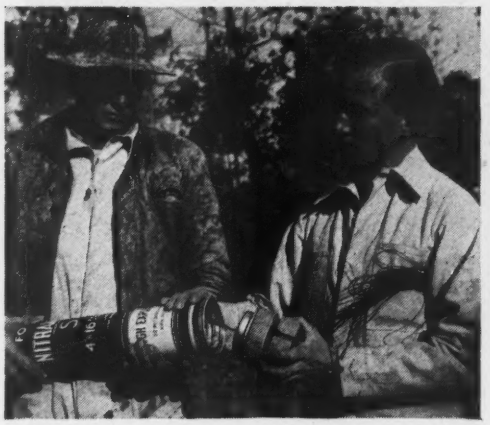

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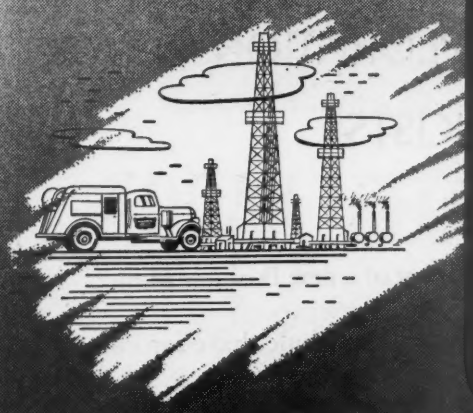

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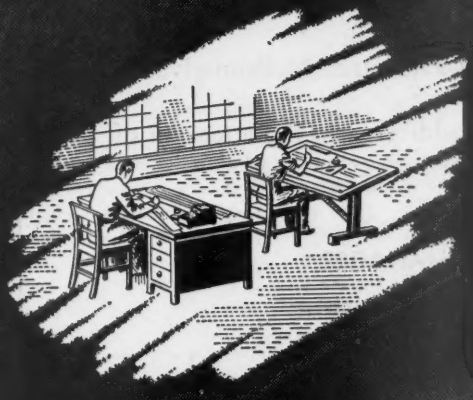

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All other correspondence should be addressed to the attention of

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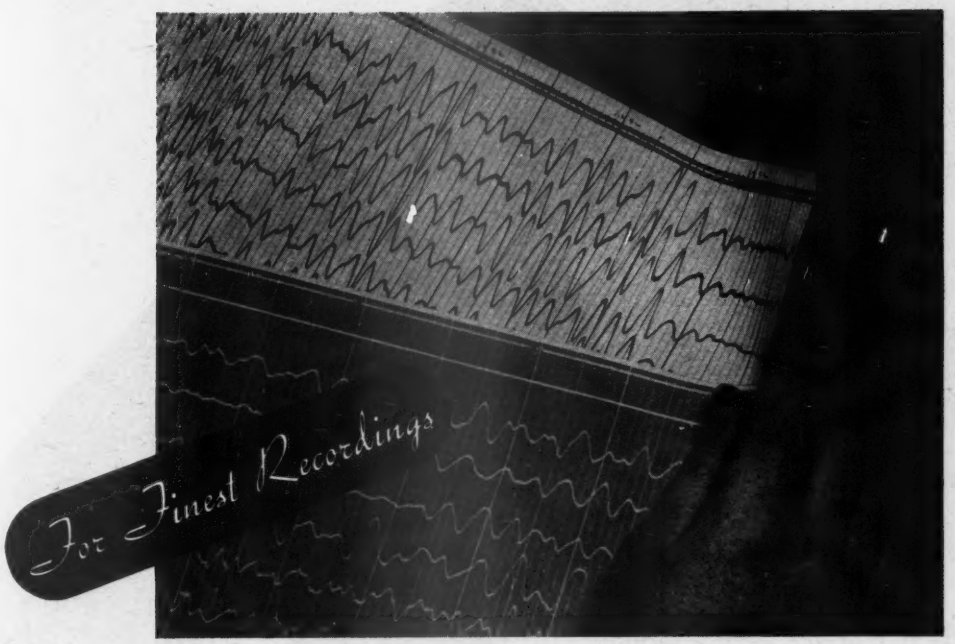

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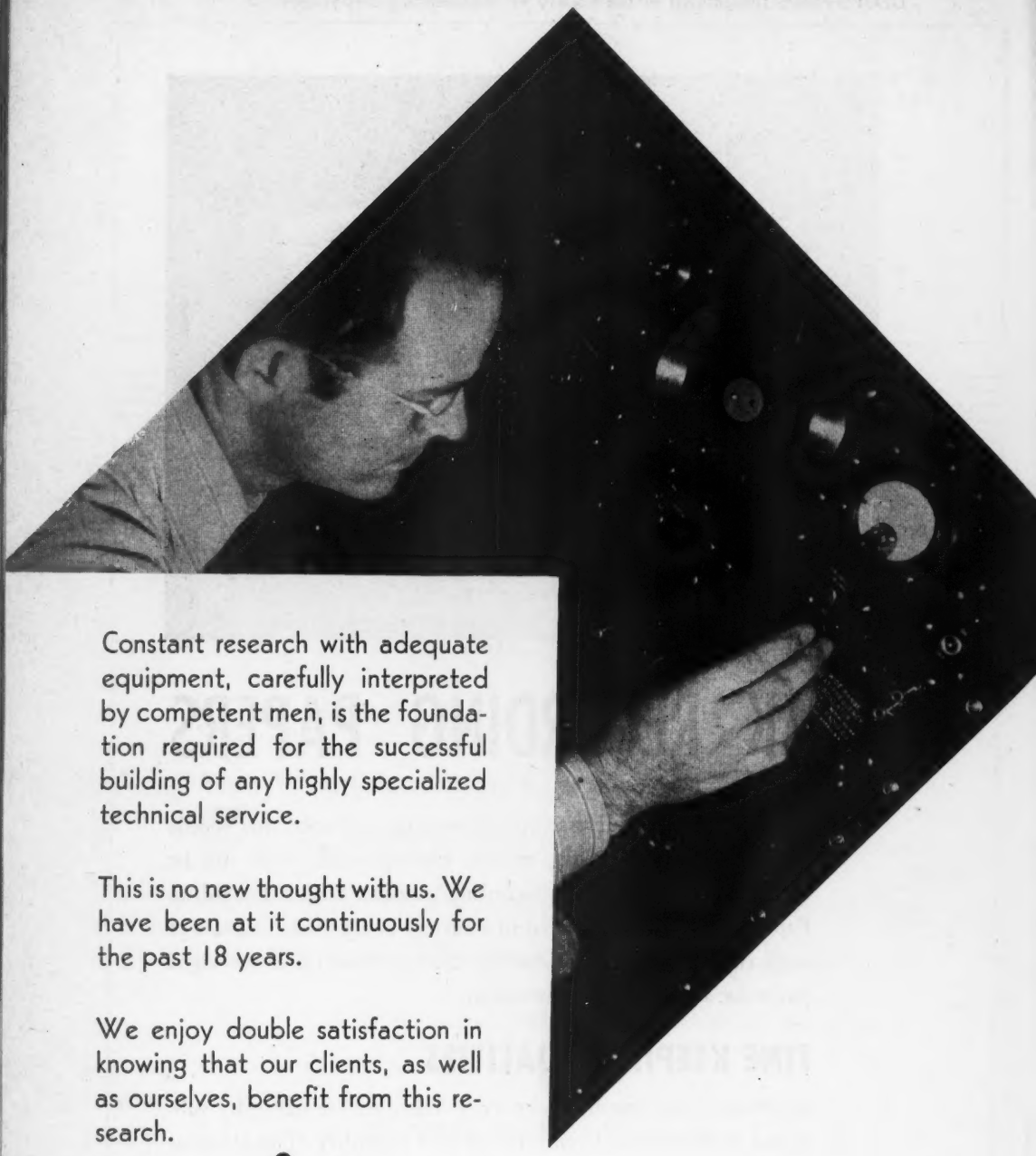

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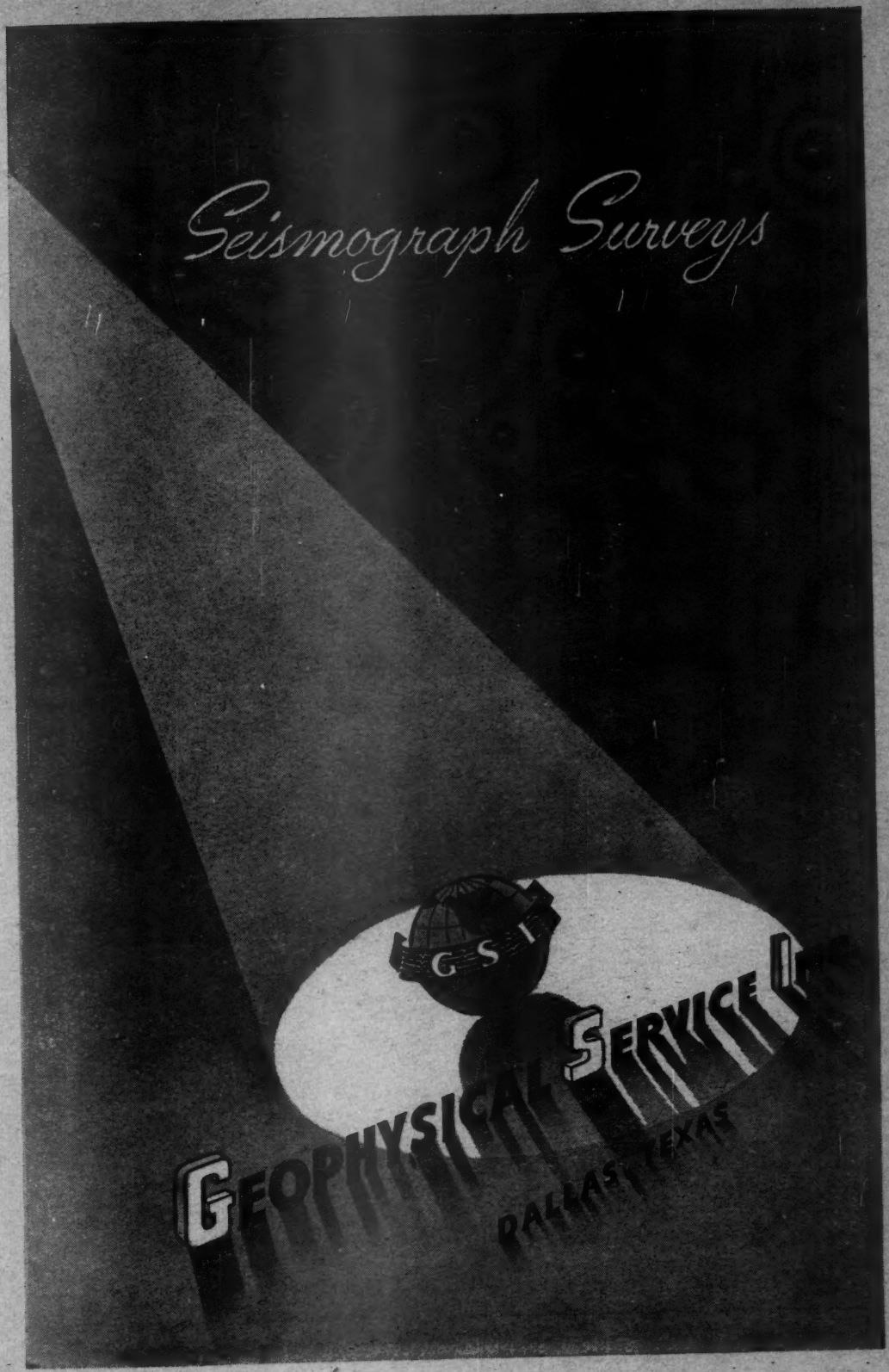
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